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by

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ABSTRACT

Kirkwood Community College, located in central Iowa, currently uses a two-stage anaerobic lagoon system for treating agricultural swine wastes. These wastes are the result of an intensified hog production facility located on the campus. The production buildings act both as a classroom and as a research facility for swine development. The material in this report focuses on the environmental impact of the two lagoons located on the college's property and adjacent to the hog production facilities.

The lagoon site has five shallow aquifer monitoring wells and three additional "geoprobe" monitoring wells installed for measuring aquifer quality. Planning and final construction of the lagoons was supervised by the Iowa Department of Natural Resources (IDNR) and finished prior to October, 1993. The initial water quality sampling program began in late October, 1993. The sampling results of each monitoring well are presented and discussed. The implications of the lagoons on the surrounding environment and human health are also considered in this report. Based on the data presented here, the lagoons do not adversely affect the quality of local groundwater resources, but they do potentially cause eutrophication in the adjoining stream. However, additional aquifer monitoring and research needs to be performed at the hog production site.

In addition to the chemicals monitored by the Iowa Department of Natural Resources, new constituents should also be monitored in the local aquifer and surface water resources to protect the environment and public health. Chemicals such as organic and synthetic feed additives and amendments are used in swine production with relatively little scientific evidence on their corresponding fate and transport characteristics. The effect of these presently unmonitored chemicals on local water quality will not be discussed in this paper.

GENERAL INTRODUCTION

Introduction

The Kirkwood Community College hog manure lagoons are an interesting application of several fields of study. The research used in this report focuses on three scientific disciplines including: Groundwater Analysis, Surface Water Modeling, and Analytical Water Quality Analysis. The use of these three areas allows a more complete and detailed analysis of the actual impact of this two-stage swine waste treatment facility on the surrounding community's water quality.

Creative Component Organization

This Civil Engineering (CE599, 2 credits) creative component is organized in a sequential fashion. The first several sections provide the necessary background information needed in the ultimate water quality analysis. Additionally, an interpretation of the data in this report is also presented to provide an explanation of the lagoons' impact on the local water quality. The remaining sections discuss and analyze the public safety and human health issues related to the operation of these lagoons.

Literature Review

Several authors have previously studied the effects of various animal waste treatment systems on water quality. J. I. Sewell evaluated the effects of a dairy lagoon treatment system on nearby groundwater quality using seven test wells located in an alluvial bottom land (Sewell 1978). Alternating layers of silt loam and sand comprised the geologic stratigraphy down to six meters. Although dairy manure is significantly different from swine waste in solids content and other chemical constituents, the geology at the site and final lagoon design were very similar to those found at the Kirkwood site. The author concluded that the lagoons had effectively "sealed" themselves and posed no major environmental or health threats to the surrounding community. Other authors found similar results when testing for contaminants from animal waste lagoons.

T. G. Ciravolo (et al.) discussed pollutant movement to shallow groundwater tables from anaerobic swine waste lagoons (Ciravolo et al. 1979). This study looked at the effect of three swine waste lagoons on groundwater quality in the Atlantic Coastal Plain region. The authors found evidence of lagoon seepage based on monitoring well concentrations of chloride, ammonia-nitrogen, and nitrate-nitrogen around all three waste lagoons. Seepage through the lagoon floor was reportedly caused by two major events. The first cause was due to gas releases from microbial activity in the sludge layer on the floor of the lagoon. These releases caused the upheaval of the lagoon bottom which resulted in the transmittal of contaminants to the underlying aquifer. Removing all lagoon liquids for irrigation or fertilizer applications was another cause of seepage. Low liquid levels caused the lagoon bottom to dry-out and crack, which eventually caused lagoon seepage. Based on the information in this study, the authors concluded low levels of overall groundwater contamination occurred from the three lagoons. Other authors studied the effect of lagoon seepage on soil and groundwater contamination.

M. H. Miller (et al.) focused their research on the accumulation of nutrients in soil beneath a hog manure storage pond (Miller et al. 1976). A storage pond is different from a lagoon. Lagoons are engineered to convert biological wastes to innocuous end-products, such as methane and carbon dioxide. Ponds are used only for the storage of agricultural wastes—not treatment. The storage pond in this study had a surface area of 2 hectares when full, approximately six times the lagoon size of the Kirkwood site. Geologic characteristics at this site consisted of a coarse textured sand with some gravel layers intermixed. Similarly, the Kirkwood lagoon geology also includes gravel and sand pockets. Miller (et al.) found no evidence of elevated chloride levels outside a storage basin in a separate study and ultimately declared unlined earthen manure ponds as “environmentally acceptable, even in sandy soil” (Miller et al. 1985). This conclusion was based on low seepage rates and minimal chemical contaminants in the monitored aquifer.

Other authors have studied the actual mechanical process of sealing in lagoons and storage ponds. J. G. Rowsell (et al.) conducted a laboratory experiment to determine sealing rates and mechanisms in earthen liquid storage manure ponds. The authors found that

infiltration rates decreased rapidly with time. The equilibrium infiltration rate, or the estimated rate when zero seepage occurs, was estimated by this study to be 1 x 10^{-8} m/s (meters/second) or less. (Rowsell et al. 1985). The Kirkwood lagoons have soil infiltration rates on the same order of magnitude, based on hydraulic conductivity analysis. The authors also found that physical blocking of the soil pores was the primary mechanism of sealing. They determined that biological activity and dispersion of soil particles were not factors in determining infiltration rates. Thus, a higher organic solids loading rate would cause less lagoon seepage and ultimately protect water quality. However, calculating lagoon seepage is difficult and requires several assumptions and mathematical equations to model and predict lagoon seepage.

Once lagoon seepage is determined, the total quantity of seepage flow plays an important role on the impact in the environment. G. Fipps and R. W. Skaggs developed seepage equations for manure liquids in both two and three dimensions for small scale ponds and lagoons on the North Carolina coast (Fipps and Skaggs 1990). The authors provide several mathematical equations for estimating total seepage quantities in both two and three dimensions. Both equations provide a reasonable estimate of lagoon seepage. However, the 2-D equation is easier to manipulate and offers solutions approximately equal to those of the more complex 3-D equation, but with less calculation time. Other studies looked at the effect of a lagoon's age on seepage rates.

Authors Huffman and Westerman looked at the seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina. They concluded that about "half of the older, unlined swine lagoons in the lower coastal plain of North Carolina are inadvertently contributing to the local contamination of the surficial aquifer" (Huffman and Westerman 1995). Additionally, Westerman, Huffman, and Feng studied swine-lagoon seepage in sandy soils in North Carolina (Westerman et al. 1995). The authors noted broad seepage plumes from the monitoring wells and concluded that the lagoons had significant seepage even after 3.5 to 5 years of waste allocation. The Kirkwood lagoons are approximately four years old and also show signs of seepage, as did the lagoons in this study.

W. F. Ritter (et al.) monitored an unlined, two-stage anaerobic swine lagoon and discussed its impact on local groundwater quality. The study monitored ammonia-nitrogen, nitrate-nitrogen, organic nitrogen, chloride, chemical oxygen demand, and total phosphorus concentrations. The authors concluded that "the lagoon did not have a serious impact on groundwater quality" (Ritter et al. 1984). The lagoon setup and monitoring analysis in this study was very similar to the situation encountered at the Kirkwood swine waste lagoons.

The Iowa Department of Natural Resources have already published their preliminary findings for the Kirkwood swine waste lagoons. Authors Quade and Libra discussed the actual signs of lagoon sealing. Several monitoring wells "showed the rising-falling concentration trend that appears to accompany sealing, other wells showed increasing concentrations during a five-year period, while yet others remained at 'background' levels throughout the monitoring" (Quade and Libra 1995).

Lagoons impact water quality in a variety of ways, either on a local scale (in the immediate vicinity of the lagoon) or with broad seepage plumes, contaminating significant portions of the groundwater aquifer. This theme is supported by recent research on the effect of lagoons on groundwater quality. However, it is this author's belief that the information presented in this study is different from previous literature studies, since it incorporates a "whole picture" analysis of the effect of swine waste lagoons on water quality and public health.

PROJECT INTRODUCTION

Problem Description

This report will accomplish several goals. First, it should help the reader decide if this lagoon system is going to have a significant impact on the surrounding environment and water quality resources outside the Kirkwood Community College's property line. Second, it will help delineate potential environmental hazards due to the unwanted seepage of contaminants from the unlined lagoons. These types of hazards may include both

groundwater and surface water contamination to the creek or to any other local water resource-user located down-stream of the creek and lagoon site. Additionally, this study will project possible contaminant levels due to the continued use of the lagoon system.

Figure 1. Kirkwood Community College hog production facilities classroom.

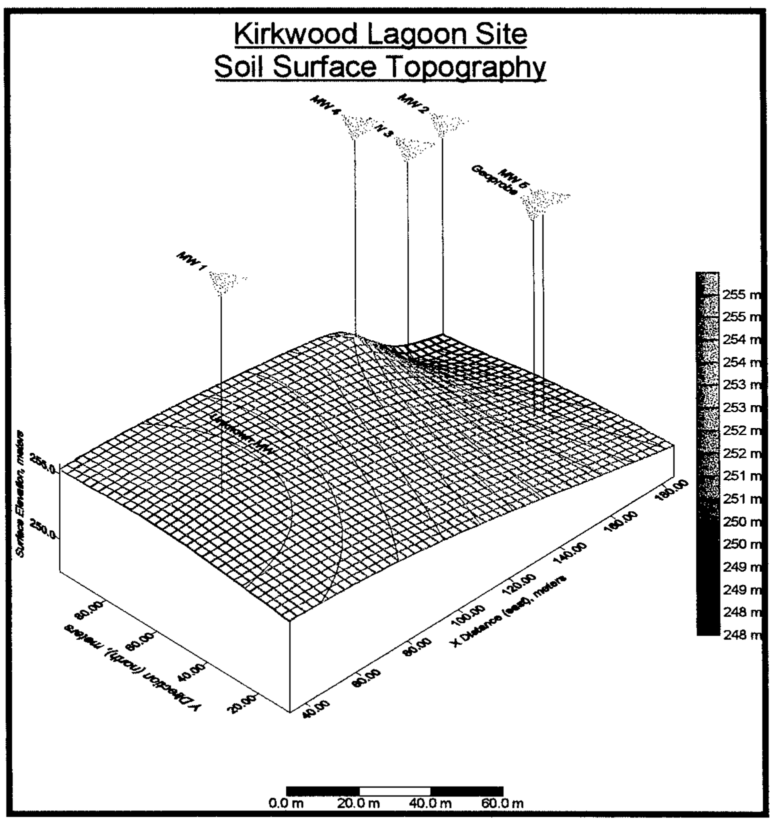


Figure 2. Kirkwood topographical site representation.

The Kirkwood hog facility (Figure 1) was designed and constructed during the beginning of this decade, in early 1993, near Cedar Rapids, Iowa. The initial orientation for the lagoons was situated to the east in a parallel line, however during construction the surface grade was found to be too steep in an easterly direction, so the Iowa DNR changed the design and oriented the second lagoon approximately five meters north of the first lagoon. See Figure 2 for site topographical representation.

The swine hog facility at Kirkwood houses about 130 farrowing hogs with an additional finishing unit sized for approximately 700 hogs (Quade and Libra 1995). See Figure 3 for a picture of the hog production facility. This facility is less than 50 meters west of the swine waste lagoons.

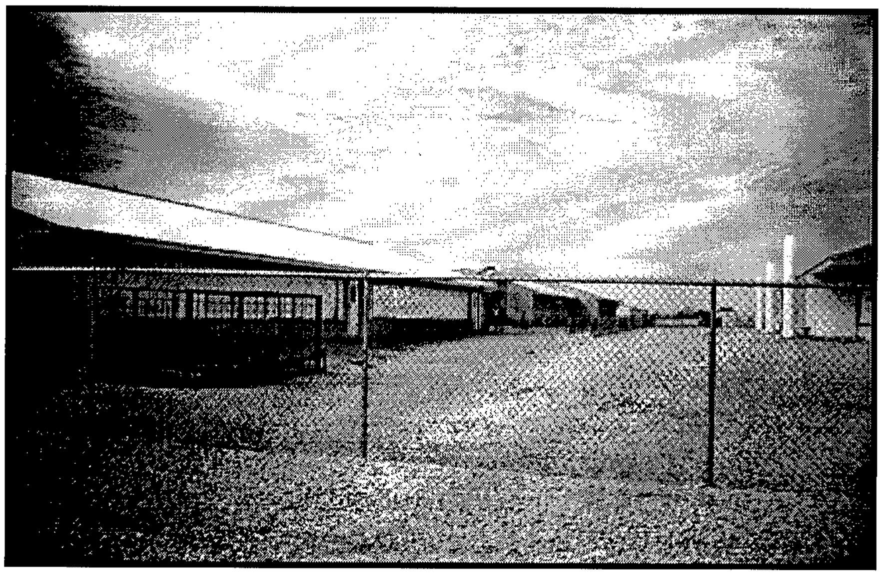


Figure 3. Kirkwood Community College hog production buildings.

Groundwater contamination is a potential problem at this site due to the seepage of organic and inorganic contaminants through the bottom and sides of the earthen swine waste lagoons. This paper will discuss groundwater quality implications from this pair of swine manure lagoons.

Additionally, potential surface water contamination is possible at this site since a small natural creek is located adjacent to the lagoons. Surface water quality issues are also addressed in this paper.

Lagoon Background

A lagoon is designed to stabilize wastes. Agricultural wastes, as defined by the American Society of Agricultural Engineering Standards, are the

> wastes normally associated with the production and processing of food and fiber on farms, feedlots, ranches, ranges, and forests which may include animal manure, crop residues, and dead animals; also agricultural chemicals and their residues and containers, which may contribute contaminants to surface or subsurface water (ASAE 1995).

Most lagoons are used to treat wastewater from municipal, industrial, or agricultural sources. "A stabilization pond (or lagoon) is a relatively shallow body of wastewater contained in an earthen basin" (Tchobanoglous and Burton 1991). Figure 4 shows the anaerobic lagoon for

Figure 4. Kirkwood Community College two-stage anaerobic hog manure lagoon (1st stage).

the Kirkwood site. Notice the biological sludge blanket contained in the corner of the lagoon. This floating layer is the by-product of microbial activity. This layer is addressed later in the paper.

The purpose of a lagoon in treating animal waste products is to biologically reduce the initial materials into stable end-products, usually involving the production of carbon dioxide or methane, depending on the specific operating parameters. Lagoons are also designed and operated to reduce organic matter and nitrogen (as ammonia) by more than 50%

(Wall 1995). The lagoon can be used in a number of manure management situations. Some lagoons provide irrigation water for crops. Other lagoons use the actual treated lagoon liquids as recycling water for flushing stalls in the hog production facility. However, all lagoons require proper engineering design and construction to prevent unwanted contamination of the area's water resources.

Lagoons with proper engineering design have several noteworthy characteristics. According to the Pork Industry Handbook, properly designed and managed lagoons "stabilize and reduce organic matter, reduce concentrations of some nutrients, adapt to a wide range of climatic and topographical situations, and are tolerant to shock loadings" (PIH-62 1993). Lagoons should always be designed with extra capacity. This additional volume is called "freeboard" and helps prevent lagoons from overflowing during periods of high surface infiltration (rainy seasons). Odors are also minimized when lagoons are designed and operated properly.

Earthen manure storage facilities are exactly that—lined with earth. There are no synthetic linings to separate the manure from soil. Thus, lagoons are prone to seepage and ultimately the possibility of contaminating the quality of the surrounding groundwater and/or surface water resources. According to the Livestock Industry Facilities and Environment publication Pm-1603,

> lagoons are used to both store and treat manure, and are much larger than earthen pits. Manure that enters a lagoon is diluted approximately 6:1 with fresh water to avoid ammonia toxicity to microorganisms that digest manure solids. Because of the dilution, the waste is much less concentrated in a lagoon than in a pit, and the volume is much greater (Pm-1603 1995).

Although seepage is a major environmental concern for lagoon usage, the dilution of animal wastes with fresh water helps minimize potential contamination hazards to underlying aquifers and nearby water resources. The environmental hazard to aquifers and surface water bodies is dampened because of the dilution effect groundwater has on incoming contaminants. This famous aquifer remediation strategy is commonly known as the "dilution solution" to contamination. Although dilution may help 'protect' the aquifer in the short-

term, the actual chemical characteristics of the seepage material is the primary concern for protecting long-term water quality resources and human health. This concern is driven by the actual lagoon design and operational parameters.

The basic design of a lagoon depends on the type of constituents entering the waste stream. Organic strength, total solids (TS), biological oxygen demand (BOD), inorganic chemical analysis, and pH are all key parameters in the analysis of the surrounding water quality due to manure storage lagoons. The Kirkwood lagoons have been monitored for chemicals such as nitrate-nitrogen, ammonia-nitrogen, organic nitrogen, fluoride, chloride, sulfate, phosphate, bromide, calcium, magnesium, sodium, and potassium. The Kirkwood site also has monitoring data for fecal matter and total organic carbon. All of this monitoring data came from five, 5.08 centimeter (2 inch) diameter monitoring wells installed by the Geologic Survey Bureau. The presence and quantity of these constituents in the Kirkwood monitoring wells is partially attributed to the operational characteristics of each lagoon. The two basic systems most commonly used in agricultural practices are either aerobic or anaerobic lagoons, or a combination of both operating schemes.

Aerobic lagoons usually have a large surface area to volume ratios. The depth of this type of lagoon is usually small compared to the overall surface area. Increased surface area is needed under aerobic conditions to facilitate aerobic oxidation and transfer within the system. Aerobic conditions are maintained throughout the depth of the lagoon by photosynthesis of algae, liquid recirculation, wind, or mechanical mixing systems. Another way to maintain aerobic conditions within a lagoon is to decrease the organic loading rate. The Kirkwood aerobic lagoon is designed essentially the same as the adjoining anaerobic lagoon, but is loaded with significantly less organic materials, thus allowing aerobic conditions throughout the system. Less organic loading helps create several advantages for aerobic lagoons.

Aerobic lagoons have the ability to destroy pathogens while anaerobic lagoons do not. Another advantage of aerobic lagoons is found in its effluent. Aerobic lagoons have higher levels of dissolved oxygen (DO) in its effluent than anaerobic systems. Elevated DO levels help reduce the immediate oxygen demand on the receiving water system or stream. This helps prevent fish kills in streams and creeks.

Anaerobic lagoons usually differ in construction from aerobic lagoons. Anaerobic lagoons, typically the most common in Iowa, are generally deeper than aerobic lagoons since oxygen transfer is not needed to maintain the anaerobic operating conditions. Anaerobic lagoons are different from aerobic lagoons since they maintain very high organic loading rates into the lagoons to ensure anaerobic conditions are maintained. Ultimately, anaerobic lagoons can be smaller in total surface area due to this significant difference in design. Other advantages of anaerobic lagoons are: anaerobic lagoons decompose more organic matter per unit volume, provide a labor savings to the farmer since liquids are easier to handle, and reduce organic solids to liquids for easy disposal (Wall 1995). However, organic loading conditions must be higher in anaerobic lagoons to maintain the depletion of oxygen necessary for anaerobic microorganisms to grow and survive. Thus, anaerobic lagoons tend to have lower degradation efficiencies. Lower efficiencies lead to higher organic levels in the effluent stream, usually greater than 10-20 mg/L as biological oxygen demand (BOD), which is higher than aerobic systems. Anaerobic systems also reduce the total nitrogen content (up to 80 %) of the lagoon liquid through denitrification (Wall 1995). Anaerobic conditions are needed for denitrification to occur. During denitrification, microorganisms use nitrate-nitrogen as a food source to produce nitrogen gas (Hoyle 1995). Ultimately, anaerobic conditions have greater odors (caused by higher organic loadings) and decrease the liquid's nutrient value to crops. Anaerobic lagoons work well in the summer, but poor in the winter when ambient air temperatures are below those needed for optimum microbial degradation. These disadvantages cause most agricultural producers to choose a two-stage lagoon system to treat their animal waste stream.

A two-stage lagoon system employs the use of both anaerobic and aerobic treatment systems. The agricultural waste stream enters the first lagoon (highest organic loading rates, i.e. causing anaerobic conditions) where biological conversion occurs under anaerobic conditions. Then the waste stream is pumped into the second lagoon where biological

There are several advantages and disadvantages for using multiple stage lagoons for treatment of agricultural wastes. According to PIH-62, advantages include: "less floating debris on the second or third stages. This can reduce the potential for clogging flush recycle

systems and irrigation pump intakes for irrigation sprinklers." This is clearly viewed in Figure 5, a picture of the Kirkwood south (aerobic) lagoon. Another advantage of multiple stage lagoons is "maintenance of a fixed minimum design and sludge storage volume in the initial cell if recycling and effluent removal are accomplished from second and third stages. This can help ensure that the lagoon system is never over-pumped (potentially causing lagoon seepage) and that an adequate concentration of bacteria are present to treat incoming manure. This allows for a more stable operation which helps minimize odors" (PIH-62 1993).

Figure 5. Kirkwood aerobic lagoon.

Disadvantages of multiple stage lagoons include "increased surface area for a given lagoon depth and volume, increased construction cost, and the potential for overloading the first cell which can lead to odors" (PIH-62 1993). In this paper, a two-stage anaerobic lagoon treatment system was designed and installed by the Iowa DNR. This two-stage lagoon system will be analyzed "from the ground up" looking at the lagoon design parameters, geology of the lagoon site, and the lagoon's impact on local water quality. Regulatory issues as well as the final engineering-based conclusions will be discussed and correlated with any foreseeable potential adverse affects to human health and safety.

SITE DESCRIPTION

Location

The confinement operation and accompanying manure lagoons of the Swine Management Program, a course offered at Kirkwood Community College, is located in Linn County, SW ¼, SE ¼, section 15, township 94, in Cedar Rapids, Iowa. In order to get to the site from Ames, Iowa, take Highway 30 east to Cedar Rapids and turn south on Kirkwood Boulevard to 72nd street. Then turn east and proceed approximately 1.6 kilometers. The hog facility and accompanying two lagoons are the last set of buildings on the north side of the road before the road turns to gravel. See Figure 6 for topographical layout of surrounding community and Kirkwood Community College Campus.

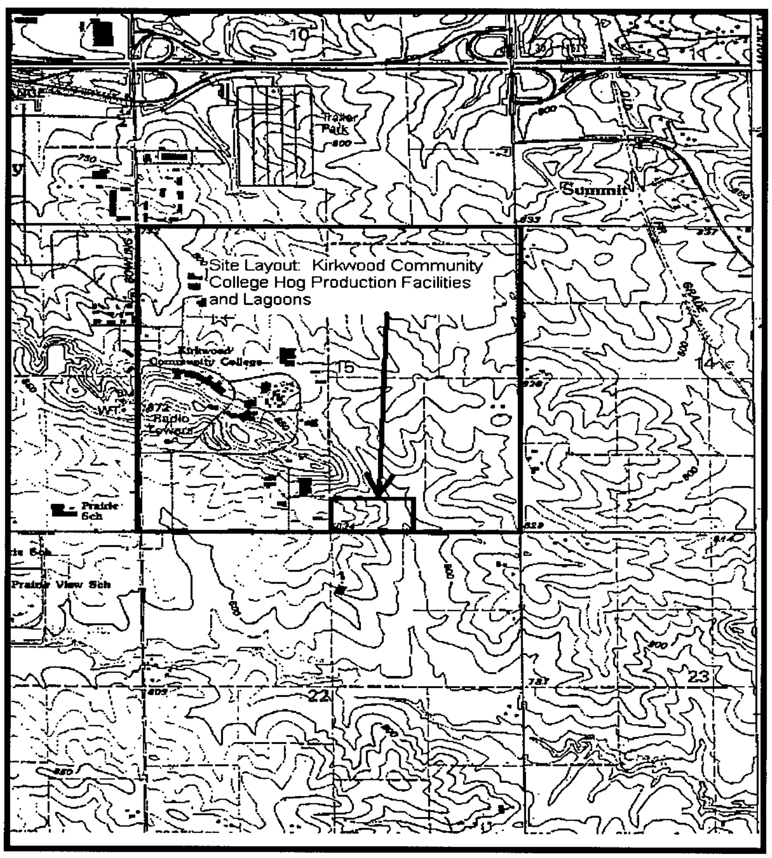


Figure 6. Topographical map of Kirkwood site.

The Iowa DNR designed the lagoons to sit within 45-60 meters east of the actual confinement operation. The site for the 0.35 hectare lagoons is remarkably clean, fully grassed around both lagoon areas, and mowed nicely. The college has also started an odor management program to control the odor around both sets of lagoons. This program is centered around using Poplar trees (See Figure 7 for a picture of lagoon wind-break), planted about 23 meters from the edge of the lagoon, as a completely enclosed wind-break. This row is followed by a row of conifer trees, which is then followed by another row of Poplar trees. This "tree-sandwich" provides a wind-break to prevent odor migration on windy days and acts as a visual shield for the lagoons from the community and passersby on the nearby street. The Poplar trees have very fast-growing root systems that are supposed to grow down, and not out, which protects the lagoon bottoms (and ultimately, their seal) from additional disturbances. The Kirkwood lagoons produced odor that could be detected downwind of the site. However, the lagoon site was manicured very well by the supporting faculty and staff.

Figure 7. Site management program at Kirkwood lagoons.

Surrounding Environmental Conditions

The trip is two hours straight east of Ames, Iowa. Rolling hills with row-crop farmland and pastures enclose the Kirkwood Campus. However, the northwest side of the

northern lagoon does have some duck-tails growing in a marshy area at the bottom of the lagoon. This might be a seepage face for the anaerobic lagoon. There is a cattle pasture east of the site that has had several applications of fresh cattle manure from the nearby Kirkwood Community College Cattle Production Facility. During the spring of 1997, after these pictures were taken, this pasture (See Figure 8) was plowed and corn was planted.

Figure 8. Surrounding environment at site.

The two geoprobes located in the pasture were 'accidentally' removed by the Kirkwood staff when this pasture was planted to corn. Thus, water table levels adjacent to the creek could not be determined. The surrounding crop land and cattle production may actually cause more environmental problems than the Kirkwood swine waste lagoons because of fertilizer, pesticide, and/or manure runoff.

LAGOON DESIGN PARAMETERS

Design Capacity

The design capacity of this lagoon treatment system is for 130 farrowing sows and 680 finishing hogs (See Figure 9). An adequate design, based on Midwest Plan Service design (MWPS-18), calls for a depth of each lagoon which is submerged below the water table, at an elevation of approximately 243 meters mean sea level (Libra 1997). This

promotes seepage of waste contaminants from the lagoon. See Appendix A—Lagoon Design for calculations.

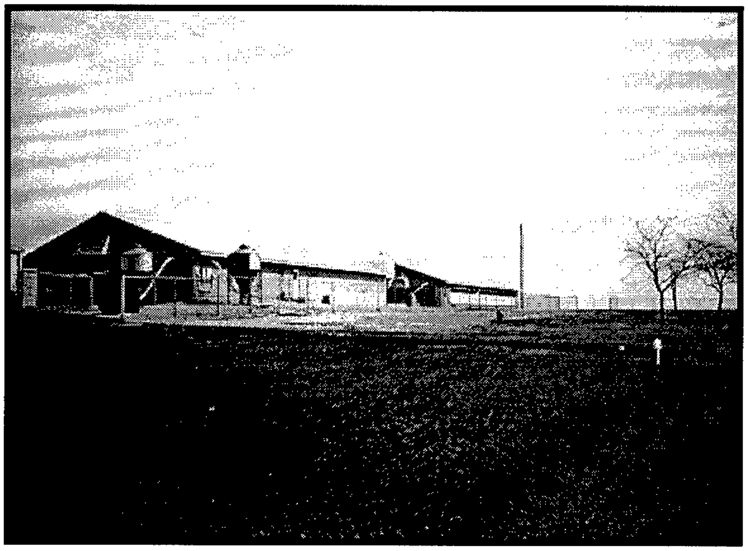


Figure 9. Hog production facilities.

The lagoon structure is unlined in both sets of lagoons. All of the hog waste goes into the anaerobic lagoon first. This lagoon is the one directly northeast of the hog

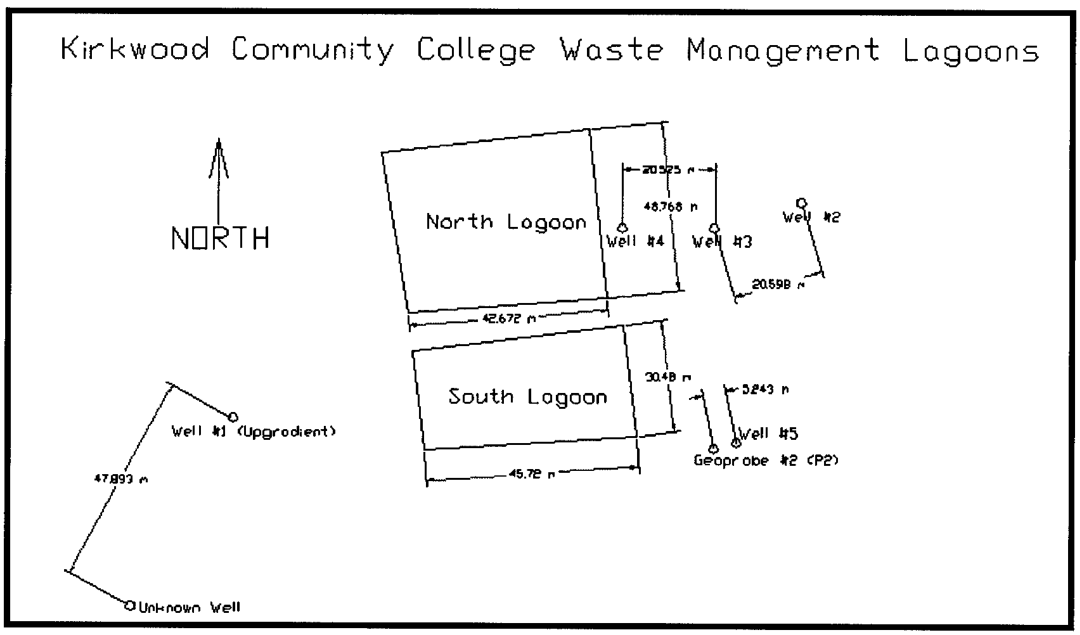


Figure 10. Detailed site layout of Kirkwood lagoons.

confinement buildings (the north lagoon) (See Figure 10). A minimum operating depth for an anaerobic lagoon must be used to ensure proper anaerobic digestion at the site. The second lagoon acts as a polishing unit for the biological treatment of agricultural waste

products from the hog production facility. Thus, there is less organic loading to the second stage than to the first-stage lagoon. These lagoons are assumed to be at steady state since the water levels when they were first measured in 1993 have stayed approximately equal between the two lagoons, at about two meters below the surface elevation with a corresponding liquid depth of approximately eight meters. The operation of these lagoons, however, is not at optimum levels.

Lagoon Operation

The actual operation of the Kirkwood lagoons is well below that of maximum capacity. This is evident in the minimum volume calculations needed for efficient lagoon operation, see Appendix A for calculations. The minimum design volume is critical to the operational success of an anaerobic lagoon. If this volume is not maintained in the lagoon, odors and other by-products of incomplete degradation can occur. According to the Livestock Industry Facilities and Environment pamphlet, "the minimum design value is the volume required to ensure efficient bacterial action for the decomposition of animal manure. The liquid level should never drop below the minimum design volume elevation. If this happens, decomposition will be incomplete, and odor problems can be expected" (Pm-1590 1995).

The minimum design volume for the anaerobic lagoon is 6140 m^3. The actual operational volume in the lagoon is 5103 m^3, nearly 17 % less than what it should be to maintain complete anaerobic degradation in the lagoon. This would explain the floating 'scum' on top of the lagoon, as described earlier and seen in Figure 11. This inefficiency could be due to lower dilution water volumes added to the manure than was anticipated during the lagoon design process. Ultimately, to reduce odor, more dilution water should be added to increase microbial degradation efficiencies of the lagoon.

The aerobic lagoon (See Figure 5) is designed and operated properly since 1610 m^3 of manure storage is needed with almost 1876 m^3 of volume available. Therefore, to make

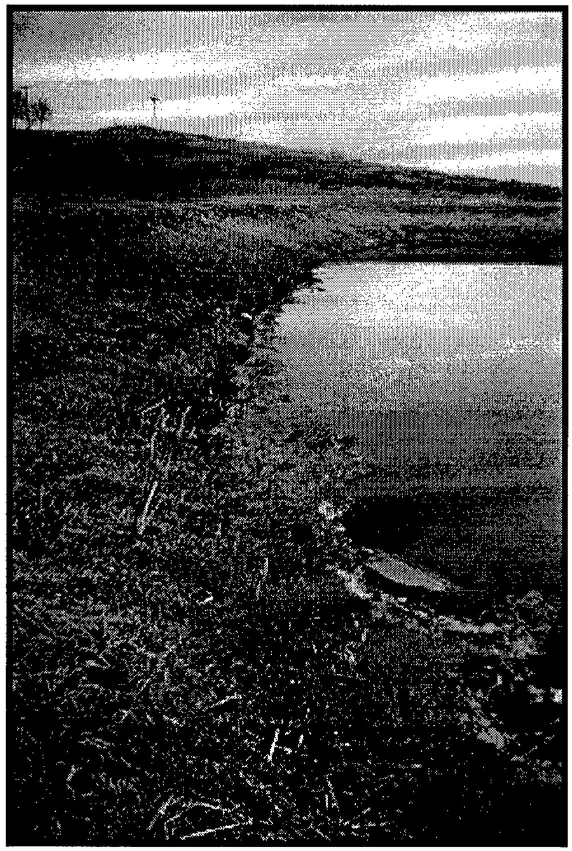


Figure 11. Incomplete degradation in anaerobic lagoon.

the lagoons operate properly, the Kirkwood operators should add approximately ten to twenty percent more volume of dilution water to the swine waste entering the anaerobic lagoon.

Characterization of waste

The physical and chemical properties of the monitoring well samples were classified by the Iowa DNR and the University of Iowa Hygienic Laboratory. Additional chemical classification was done using the equipment from the Iowa State University Toxicology laboratory on several MW and stream samples. Stream samples are discussed in the surface water quality section.

The Kirkwood anaerobic lagoon (north lagoon) and aerobic lagoon (south lagoon) were both sampled for nitrate-N, ammonia-N, chloride, total phosphate, and sulfate concentrations during March, 1996. These levels help describe base-line conditions in the lagoon. Ultimately, when levels in the surrounding monitoring wells reach these base-line concentrations, seepage will have caused an equilibrium between the actual lagoon liquids and aquifer contamination levels. Both sampled lagoon results are listed in Table 1.

Lagoon	Chloride, mg/L	Sulfate, mg/L	Ammonia-N, mg/L	Nitrate-N, mg/L	Phosphate, mg/L
Anaerobic (north lagoon)	360	9.8	310	0.3	70
Aerobic (south lagoon)	190	9.4	170	0.5	29

Table 1. Lagoon characteristics.

Based on the chemical analysis, ammonia-N concentrations in the lagoons are significant and could pose an environmental hazard if converted into nitrate. Ammonia-nitrogen in its immobile form NH_4^+ (due to cation-exchange with clays) can be biologically converted into nitrate-nitrogen, the most mobile form of nitrogen in aquifers, based on current literature (Korom and Jeppson 1994). Therefore, of the chemicals analyzed in this study, nitrate-nitrogen is of primary concern due to its transport abilities. "The accumulation of NH_4-N in the soil below a lagoon or feedlot is not detrimental as long as it remains as NH_4^+. If, however, the lagoon or feedlot were abandoned and the soil became aerobic, extremely high levels of nitrate could occur and present a serious hazard to local water supplies" (Miller et al. 1976). Although ammonia levels are low in the monitoring wells, potential aquifer contamination could result from over pumping the lagoons (allowing oxygen to reach the soil and ultimately leach nitrate) or completely abandoning the lagoons from future use. The Kirkwood site, a long-term hog production facility, performs scheduled and monitored lagoon pumping, approximately once per year (Libra 1997). Ammonia-nitrogen is safe under the Kirkwood anaerobic lagoon from aerobic conditions and the potential for conversion into the hazardous nitrate-nitrogen.

The anaerobic lagoon water was extremely dark, almost opaque. The water had the rough appearance of chocolate milk and was filled with floating biological microorganisms. The second-stage lagoon (aerobic) water looked very clear. There was virtually no floating biomass material on top of the water, giving it the appearance that it was operated well, which is true, due to the low organic loading rates entering the anaerobic lagoon. The Kirkwood site does not utilize high organic loading rates into the lagoons due to the relatively small nature of the hog facilities and its less than maximum animal waste production rates. Thus, the lagoons are actually over-designed for the treatment of the Kirkwood swine wastes. The first-stage lagoon (anaerobic) had some biological decay products or filaments growing on the surface of the lagoon. At one time, managers of this lagoon used the floating layer as a means to control odor. However, windy days and other adverse climatic conditions disrupt this biological layer and contribute to the lagoon's odor problem.

In addition to the Iowa State University Toxicology laboratory, the University of Iowa's Hygienic Laboratory performed chemical analysis of samples taken from both the lagoon water and the monitoring wells, but not from creek samples. Several organic and inorganic constituents were analyzed. Fecal organic matter, nitrate-nitrogen, ammonia-nitrogen, organic-nitrogen, total organic carbon, fluoride, chloride, and sulfate concentrations in each well were quantified on a monthly basis starting in October, 1993. The Iowa DNR continues the sampling today, however, sampling frequency has slowed to a quarterly pattern. See Appendix B for complete chemical analysis of the Kirkwood lagoon's monitoring wells.

Monitoring Well #1 (MW1) (See Figure 12) indicates a decreasing chloride and nitrate-nitrogen concentration, while sulfate and total organic carbon (TOC) concentrations appear to be increasing at a gradual rate. This wells is considered a background well since it is up-gradient from the lagoons. Typical background chloride concentrations are 15-30 mg/L, which is representative of the Kirkwood site. Ammonia-nitrogen concentrations began erratically immediately following lagoon start-up, but have remained constant for the last two years of monitoring.

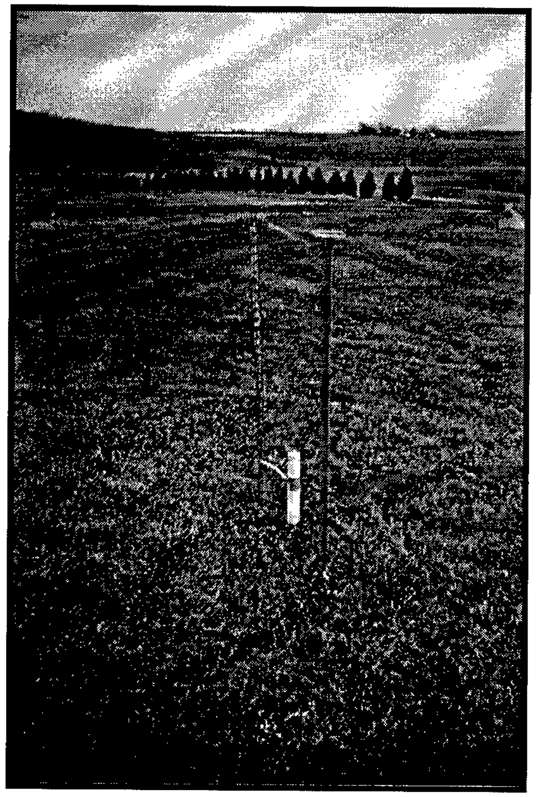


Figure 12. Monitoring Well 1.

Chemical concentrations at Monitoring Well #2 (MW2) are significantly different from those trends set by MW1. Nitrate-nitrogen concentrations originally decreased, but during April 1996, concentrations began climbing, but are still well below 1.0 mg/L. According to Quade and Libra, this type of erratic concentration levels are indicative of lagoon sealing (1995). Chloride concentrations are also increasing, with levels near 150 mg/L. Total organic carbon levels are also rising, indicating a potential for colloidal transport in the underlying aquifer. However, as with MW1, ammonia-nitrogen levels are remaining constant at, or below detection limits of 0.1 mg/L. Sulfate levels are also decreasing slightly and are well below the United States Environmental Protection Agency's (USEPA) secondary maximum contaminant level of 250 mg/L (Montgomery 1985).

Monitoring Well #3 (MW3) shows a drastic reduction in nitrate-nitrogen concentrations, but a slight increase in NO_3-N levels after the November, 1996 sample. Additionally, ammonia-nitrogen levels are also showing an increasing trend. Similar to MW1 and MW2, sulfate levels are decreasing. The biggest indicator of potential lagoon

seepage and aquifer contamination at MW3 is in the sampled chloride levels. Chloride concentrations are rising exponentially to levels near 200 mg/L. Total organic carbon levels are increasing, also indicating the potential for colloidal transport of chemical contaminants.

Monitoring Well #4 (MW4) has several erratic chemical indicators. Total organic carbon levels are oscillating between high levels near 400 mg/L to levels close to 0 mg/L. However, a general trend indicates increasing TOC levels. Nitrate-nitrogen concentrations are also behaving erratically, varying from levels near 0.6 mg/L to levels at or below detection limits of 0.1 mg/L. Chloride levels are following a more consistent pattern than the other constituents. Chloride levels are rapidly approaching 350 mg/L, concentrations near lagoon background amounts. Ammonia-nitrogen levels are also climbing rapidly to near 1.0 mg/L. Sulfate levels are decreasing slowly to near 10 mg/L, well below EPA standards and secondary standards. This lagoon appears to have sealed itself with respect to ammonia-N and nitrogen, but is still seeping lagoon liquid—as seen by rising chloride concentrations. This lagoon appears to have a biological sealing process occurring with nitrate-N converted to nitrogen gas by denitrification. However, constituents not anaerobically degraded (like chloride and possibly other organic chemicals) could be infiltrating the aquifer causing environmental contamination.

Chemical concentrations in Monitoring Well #5 (MW5) have remained relatively unchanged since sampling procedures were started in October, 1993. Nitrate-nitrogen levels have slowly decreased in an approximately linear fashion from levels of about 15 mg/L to less than 1 mg/L. Ammonia-nitrogen levels have also "base-lined" at or below the detection limits of the hygienic laboratory at 0.1 mg/L. Chloride levels are slightly increasing to concentrations near 100 mg/L. Sulfate concentrations however, are remaining relatively unchanged at approximately 50 mg/L. Total organic carbon levels also indicate a slight rising trend with levels approaching 200 mg/L. Although the chloride concentration in the aerobic lagoon is almost half those values in the anaerobic lagoon, the recorded chloride concentrations in this well indicate a couple of things. Either less total seepage from the lagoon or a greater amount of aquifer dilution is dampening the chloride response in MW5 from those felt by MW4.

The monitoring wells sampled at the Kirkwood site show definite signs of biological activity—both in the lagoons and within the aquifer itself. In MW1, the initial levels of ammonia-nitrogen are quickly used up in the conversion of ammonia-N into either biomass for microbial growth or into nitrate through the nitrification process—an aerobic process (Hoyle 1995). Then, as the system becomes more anaerobic due to the high organic loading rates in the lagoon and liquid depth, nitrate-nitrogen is ultimately converted to nitrogen gas as denitrification occurs under anoxic conditions. Fine-grained aquifer material found at the Kirkwood site is a prime location for denitrification, since little oxygen can diffuse into the water-filled pore spaces. Data on "nitrate-nitrogen concentrations indicated that there was very low denitrification potential in coarse-textured profiles and that the nitrate-nitrogen concentration and movement were dependent on water movement and amounts of nitrate available for leaching" (Devitt et al. 1976). This is evident by the decreasing nitrate-N concentrations seen in MW1. The clay layers limit the groundwater flow through the soil media, reducing the leaching fraction of nitrate available and consequently, initiating anaerobic conditions in the aquifer. These conditions are needed for denitrification to occur.

Monitoring Well #2 and #3 also display signs of biological activity. On the graph of nitrate-nitrogen versus ammonia-nitrogen, clear evidence of biological activity is present. First, as the nitrate levels increase (nitrification), ammonia levels decrease through the conversion of it into nitrate. Then, nitrate levels decrease while ammonia levels increase, demonstrating anaerobic conditions since denitrification is removing nitrate from the system. Ultimately, nitrogen is lost from the anaerobic lagoon.

Monitoring Well #4 also shows signs of aerobic activity. This is indicated by the opposite response pattern of nitrate and ammonia. As nitrate levels increase, ammonia levels decrease as aerobic respiration converts ammonia to nitrate (nitrification). Then, as anaerobic conditions occur, nitrate levels decrease while ammonia levels increase since there is no conversion of ammonia into nitrate by aerobic respiration. Ammonia levels appear to be increasing significantly in 1997, which could indicate that the cation exchange capacity of the soil under the lagoon has reached saturation. Future ammonia-N levels could continue to

rise with this break-through situation, causing increasing potential nitrate-N production and aquifer contamination.

Monitoring Well #5 illustrates a near complete conversion of nitrate into nitrogen gas with ammonia levels near zero. This illustrates an anaerobic condition with what appears to be little or no seepage into the well, due to the relatively stable chloride levels sampled in the well.

The nitrate-nitrogen versus chloride ratio is another analysis tool to demonstrate microbial activity in an aquifer. The NO_3^-N/Cl^- ratio decreased in all monitoring wells, including MW #1 (background well). "If one assumes that chloride and nitrate-nitrogen move in the water in a similar fashion and that neither reacts with soil to any significant degree, then the ratio should be fairly constant" (Devitt et al. 1976). The chloride anion is a non-reactive, conservative (no losses due to chemical reactions or biochemical degradation) tracer ion. The nitrate-nitrogen anion can be lost due to biological conversion, such as in denitrification. Thus, if *no* biological activity were present, the NO_3^-N/Cl^- ratio should remain constant. In a separate study of nitrate-nitrogen movement through soil, "the data suggest denitrification occurring in the lower parts of the profile where clay content became relatively high" (Devitt et al. 1976). The Kirkwood soils under the lagoons have relatively high clay contents (7 to 27 %) based on analysis of USDA soil surveys. This may be why the monitoring wells at the Kirkwood site show a definite decrease in nitrate levels when compared to chloride levels. Microbial denitrification is the primary culprit to these decreasing trends in nitrate-nitrogen concentrations. However, monitoring well #1 (up-gradient well) also demonstrates denitrification characteristics. This could be caused by greater aquifer dilution at MW1. Another explanation for denitrification in MW1 is that the screening interval for the well is located in a clay layer with little potential for oxygen and aerobic respiration. These could cause anaerobic conditions, which are necessary for denitrification to occur.

Lagoon Design Requirements

Iowa's current "Animal Feeding Operations" rules, found in Chapter 65 of the Environmental Protection Commission, Section 567 of the Iowa Administrative Code, became effective in July of 1987. This updated the old regulations from 1969. Ideally, these restructured environmental regulations will help reinforce environmental awareness and stewardship within the animal production community. Although not discussed in this paper, animal production, odor control, and waste treatment are largely political issues in Iowa and by far, the largest motivating factors in Iowa environmental regulations. This means that animal waste lagoon design and construction are significantly impacted by these new regulations.

Iowa's environmental regulations define anaerobic lagoon as "an earthen impoundment designed and operated to provide both long-term storage and partial treatment of animal wastes from a confinement feeding operation. The IDNR rules require that anaerobic lagoons meet specified design criteria and that a portion of the wastes be removed from the lagoon and disposed of by land application at least once annually" (Agena et al. 1992). The type of lagoon and animal feeding operations at the Kirkwood Community College hog production facilities warrants regulation under Iowa law.

The Kirkwood site uses a totally roofed animal feeding operation with all wastes either stored or removed as a liquid or semi-liquid material. Therefore, the Kirkwood site is classified under Iowa law as a "confinement feeding operation." (Iowa House Bill 50.1 1995; Department of Natural Resources section 455B.173). Any producer under these conditions must follow several rules. First, confinement feeding operations are required to collect and store all wastes produced in the operation, including wastes produced between periods of waste disposal. These feeding operations usually dispose of their stored wastes by land application, either in irrigation or liquid fertilizer form. Second, earthen waste control structures such as, anaerobic lagoons, aerobic lagoons, and earthen waste slurry storage basins, must have wastes removed from the structures as needed to maintain a minimum of 0.61 meters (2 feet) of freeboard, unless additional freeboard is necessary to protect the structure or prevent waste discharge. The bottom of the lagoon must also be at least 0.61

meters above the highest ground water level (Pm-1590 1995). The Iowa DNR may also approve other methods of disposal as long as they are feasible and do not pose a threat to public health or the environment. The IDNR prohibits the direct discharge of wastes from confinement feeding operation into state waters. This includes discharge to a publicly owned lake, a sinkhole, an agricultural drainage well, or to tile lines that drain into state waters. Additionally, all wastes removed from a confinement feeding operation, or its waste control facilities, must be disposed of on land in a manner that does not cause surface or groundwater pollution. When discontinuing a confinement feeding operation, all wastes from the feeding operation and its waste control system must be removed and disposed of on land as soon as practical (but not more than six months) after closure. Finally, the Iowa DNR may require a greater level of waste control from a confinement feeding operation if it is determined, following an on-site inspection, that the minimum level of waste control is inadequate to prevent water pollution. (Agena et al. 1992)

Iowa law also defines regulations for construction and site selection of animal waste lagoons. Additional requirements for confinement feeding operations include gaining construction permits and specifying separation distances. A construction permit is needed, regardless of size, for any operation that uses an anaerobic lagoon as any part of their waste control system. Anaerobic lagoons or earthen waste slurry storage basins, used as part of a confinement feeding operation, must be located at least 381 meters (1,250 feet) from residences not owned by the swine production operation and from public use areas (other than roads) if the operation contains animal species other than beef cattle and has a capacity of less than 283,500 kg (625,000 pounds) of live animal weight. (Agena et al. 1992) The Kirkwood site has a capacity almost one-third of this regulated maximum level. Since the hog manure lagoons are situated next to the other Kirkwood College facilities (which the school owns), no permits are required to maintain compliance with Iowa law.

Currently, several legal guidelines exist for the management of swine manure. One of the biggest issues facing regulatory intervention is odor. Odor problems arise from anaerobic decomposition of animal wastes and can cause nausea, watery eyes, and loss of appetite at concentrated levels (PIH-35 1994). According to Price (et al.), “most problem-causing

conditions occur in the lagoon at the time of spring [ice] breakup. The anaerobic conditions that have prevailed over winter produce a population of a sulfur-reducing bacteria *desufovibrio* that reduces sulfates to hydrogen sulfide, and if the pH is low (algae have not established an aerobic zone and higher pH) the hydrogen sulfide will escape into the atmosphere causing odor problems" (1995). Rising spring temperatures and wind may cause the lagoon to turn over or mix several times, causing additional odor problems. (Price et al. 1995) Thus, odor control has become a major concern within the hog production industry to prevent adverse litigation.

One method to reduce odor problems is to increase the size of the lagoon. DeKalb Swine Breeders Inc., of Fredricksburg, Iowa, used the standard loading/volume considerations during the lagoon design process, but then doubled the required size of the lagoon in order to reduce foul odors produced by slug loading and seasonal temperature changes (Wall 1995). No evidence was found that this type of consideration was applied at the Kirkwood lagoons.

Private regulation of pollution from hog production facilities has taken many forms, including lawsuits based on trespass, negligence, or invasion of riparian water rights and nuisances. Both public and private nuisances exist. Public nuisances are defined as "an interference with a right common to the general public" (PIH-35 1994). This could be an action that threatens people's health or safety, including problematic odors originating from a hog production facility. A private nuisance is something that "makes it difficult for neighbors to live there" (PIH-35 1994). Hog production activities that cause odors, dust, flies, or other contamination are all considered nuisances.

Another requirement for lagoon design and construction deals with infiltration rates. Maximum infiltration rates must be less than a predetermined level, set by the state environmental regulatory agency. Testing of infiltration rates is required after construction, but before liquid wastes can be added to the lagoon. Several states regulate infiltration rates, including Iowa. Iowa's maximum infiltration rate is 0.16 cm/day at a water depth (head) of 1.8 m (Pm-1590 1995). Other requirements for the state include: "a minimum of three soil borings are required for lagoons smaller than 0.2 ha, and four or more borings for lagoons

greater than 0.2 hectares. Minimum depths of the borings are 3 m below the bottom elevation of the lagoon, with at least one boring extending 7.6 m in depth. Additionally, earthen waste control structures are required to have a minimum freeboard of 0.61 meters" (Parker et al. 1994). Other states regulating infiltration rates to lagoons include: Missouri (infiltration=0.042 cm/d to 0.29 cm/d), Colorado (infiltration=0.08 cm/d), Nebraska (infiltration=0.63 cm/d), and Kansas (infiltration=0.63 cm/d) (Parker et al. 1994).

The Kirkwood lagoon site is larger than 0.2 hectares. Thus, a total of five soil borings were performed during the lagoon construction. All soil borings were analyzed following the construction of monitoring wells one through five. Average soil background chloride concentrations were approximately 72 mg/L with a range of 13 mg/L to 102 mg/L, with most levels near 50 mg/L. Soil pH values averaged 7.3, or just slightly basic. Additionally, average ammonia-N concentrations were about 200 mg/L, and average sulfate levels of 425 mg/L were significantly above EPA secondary drinking water standard of 250 mg/L (Montgomery 1985). All constituent levels are within acceptable standards for background concentrations, except for sulfate. Concentrations of 400-500 mg/L of sulfate produces a laxative effect in humans (Montgomery 1985). However, after the lagoons were installed, anaerobic microbial conditions developed. The anaerobic condition in the area immediately surrounding the lagoons caused the reduction of sulfate into hydrogen sulfide gas, consequently, total sulfate levels also decreased in the monitoring wells. Careful analysis of site geology and accompanying hydraulic characteristics are of primary importance in determining the ultimate fate and transport of these contaminants in surrounding water systems.

GEOLOGY OF SITE

Geologic Site Description

The Kirkwood site is situated on the Iowa Erosion Surface. This geologic surface was formed during the Wisconsin glacial stage by glacial out-wash and erosion. (Anderson

1983). The geologic history of this site is very complex. Therefore, the following discussion is a brief synopsis of the geologic history of Iowa from about 4 ½ billion years ago to the present time. This review is necessary to fully appreciate the stratigraphy of the geologic material underlying the Kirkwood Community College animal waste lagoons and its impact on water quality.

Throughout most of the state of Iowa, the bedrock layer is covered with various deposits such as sand, gravel, silt, clay, and loess. The geologic periods that help define Iowa's soil and rock record are the Precambrian, Cambrian, Ordovician, Silurian, Devonian, Mississippisan, Pennsylvanian, Jurassic, Cretaceous, and Quaternary. (Anderson 1983.) The Precambrian layer is the oldest rock formation, from about 4 ½ billion years ago to 570 million years ago, while the Quaternary period is from a more 'recent' era (Cenozoic) of only 2-3 million years ago. The Cenozoic era has deposits from both the Pleistocene Ice Age and Recent Epochs. These geologic periods are responsible for most of the soil deposits to the Iowan surface.

Iowa's rock record is composed primarily of layered sedimentary rocks. "The Quaternary system consisted of several geologic formations including: Wisconsin, Illinoian, Kansan, and Nebraskan" (Anderson 1983). Of these formations, the Illinoian is of primary importance at the Kirkwood Community College site since it is the formation through which each monitoring well and 'geoprobe' is screened (See Figure 13). The geology of this formation will play a major role in hydraulic conductivity analysis and contaminant transport modeling.

Figure 13. Geoprobe monitoring well.

The age of this formation is approximately two to three million years before the present time. These formations are predominantly composed of loess, glacial till and interbedded sand and gravel. Glacial till is defined as the "sediment deposited directly from the ice. Till is characteristically poorly sorted material. Some of the till may be transported and redeposited by the melt water, whereupon the sediment is called outwash. Till and outwash together are two varieties of glacial drift" (Montgomery 1989). The average thickness of the glacial till layer is approximately 150 meters. See Figure 14. Ultimately,

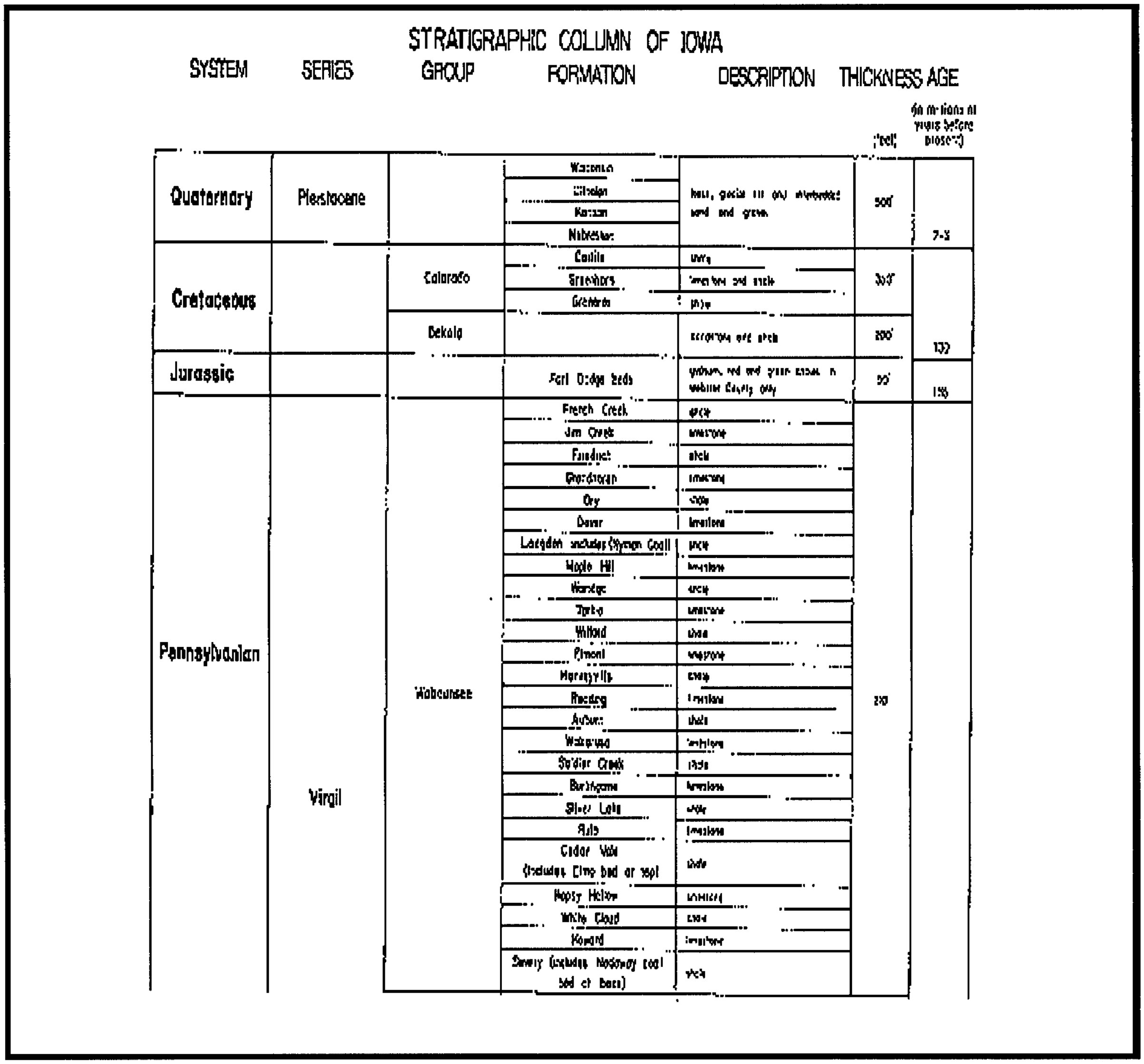


Figure 14. Partial stratigraphic column of Iowa (Anderson 1983).

any monitoring well installed within this layer will be encountering geologic and hydrogeologic properties of the Quaternary period. It was during this period that most of Iowa's rich, fertile soils were formed.

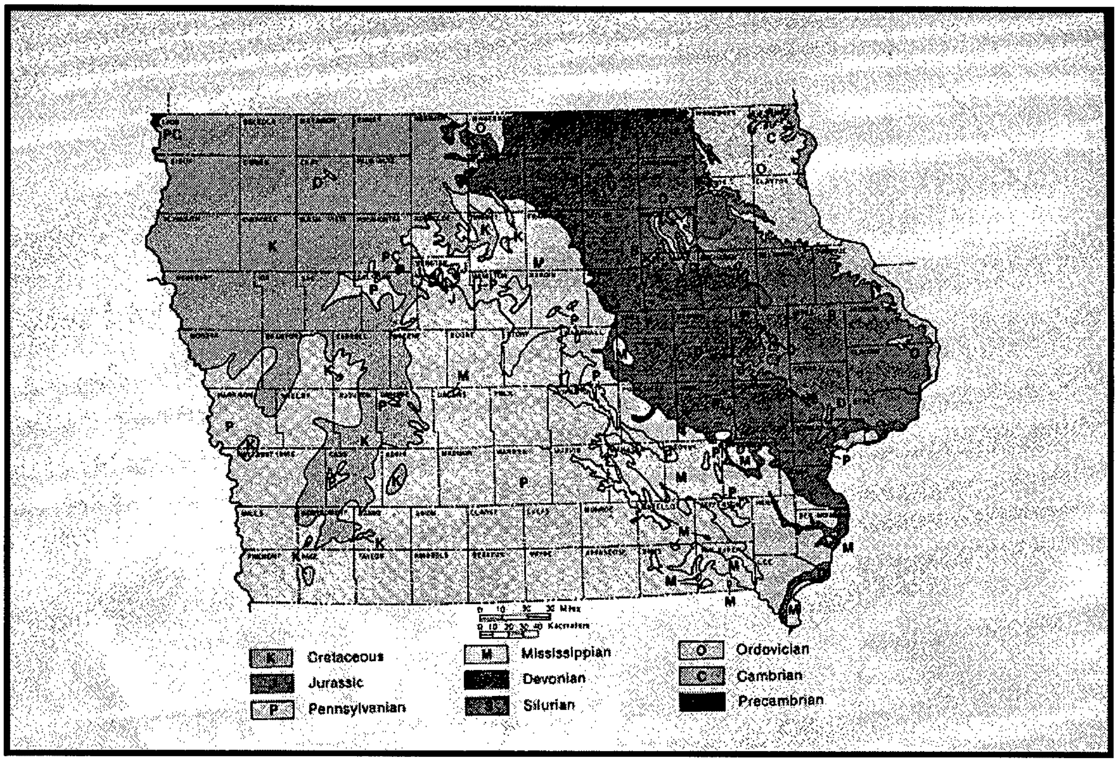


Figure 15. Iowa bedrock formations (Anderson 1983).

The remaining layers of geologic material alternate between shale and limestone bedrock. See Figure 15 for the bedrock formations in Iowa. Iowa's geologic history started long before the widespread farming revolution began during the late 1700's and early 1800's. Long before corn, soybeans, and cattle pastures, prairie grasslands and scattered forests existed. Even earlier,

> "during the Pleistocene Ice Age, Iowa was alternately covered by continental glaciers and evergreen forests. If we go back beyond the Pleistocene Ice Age to the Mesozoic time, we find that Iowa was covered by a shallow sea particularly similar to the modern Gulf of Mexico. Still earlier, in Mesozoic time, Iowa's environment resembled the saline lagoons of the present day Persian Gulf.
>
> Ancient Iowa in Paleozoic time experienced a variety of coastal plains and shallow marine environments similar to those found along the modern coasts of Texas, Louisiana, and Florida. Coastal swamps, deltas, like those of modern-day

Louisiana, existed during the Late Paleozoic time when Iowa's coal deposits were being formed.

Iowa's most ancient rock record, the Precambrian, is difficult to decipher; yet the record can be interpreted in general terms. During part of the Precambrian time, Iowa rested on the floor of a shallow sandy basin. At other times during the Precambrian, Iowa was located along a rift-valley system like that of present-day Africa. Still earlier, in Precambrian time, Iowa was apart of an ancient mountain belt in which granite and granite gneiss (or irregular mineral band) were formed" (Anderson 1983).

Several other features about Iowa's geologic history are important to the Kirkwood lagoons. Under the Pleistocene Ice Age mantle of unconsolidated till, lies a significant layer of dolomite. Dolomite is formed in magnesium-bearing waters of the old seas that covered Iowa by reacting the water with calcium carbonate minerals of the limestone bedrock to form the calcium-magnesium carbonate mineral, dolomite. (Anderson 1983). Dolomite materials can have a large impact on contaminant transport due to the increase in rock porosity. "In nature, when calcite is converted to dolomite, there is a resulting increase in the void space of the rocks. The void space (porosity) can take the form of molds, representing space formed by the solution of calcium carbonate fossils, or the porosity may exist in the space between the loose-fitting dolomite crystals" (Anderson 1983). Thus, the effective porosity of these types of soils might be significantly higher than anticipated, due to the increased void space around structural crystals. However, as previously stated, the majority of geologic interest is centered on the Pleistocene era—the Ice Age. This is when mammoth glaciers deposited the layer of till on Iowa's surface.

The bedrock formations are an important Iowan feature that must be analyzed below the Kirkwood site. These formations could play a major role in contaminant transport from the lagoons to the groundwater if fractures or other alternate flow-paths exist, which might facilitate contaminant transport across the lagoon boundaries. However, since all monitoring wells are installed to depths less than nine meters, fractured bedrock flow will not be discussed further.

As previously stated, soil development in Iowa is attributed to the deposits of glaciers. According to Anderson, "the principle parent materials of Iowa soils are: 1) glacial drift, 2) loess, and 3) alluvium. Drift, loess, and alluvium are all materials that were previously weathered before they were transported and deposited. Glacial drift and loess deposits each served as the parent material for about 40% of Iowa's soils" (1983). Thus, glaciers and wind transport of soil each contributed to Iowa's rich and fertile soil development, in addition to the formation of water bearing aquifers.

Several aquifers lie under the Kirkwood site. Due to the geologic deposition of glacier materials, several alluvial aquifers exist in Iowa. See Figure 16 and Figure 17 for the aquifers in Iowa as well as the major alluvial aquifers that exist in Iowa.

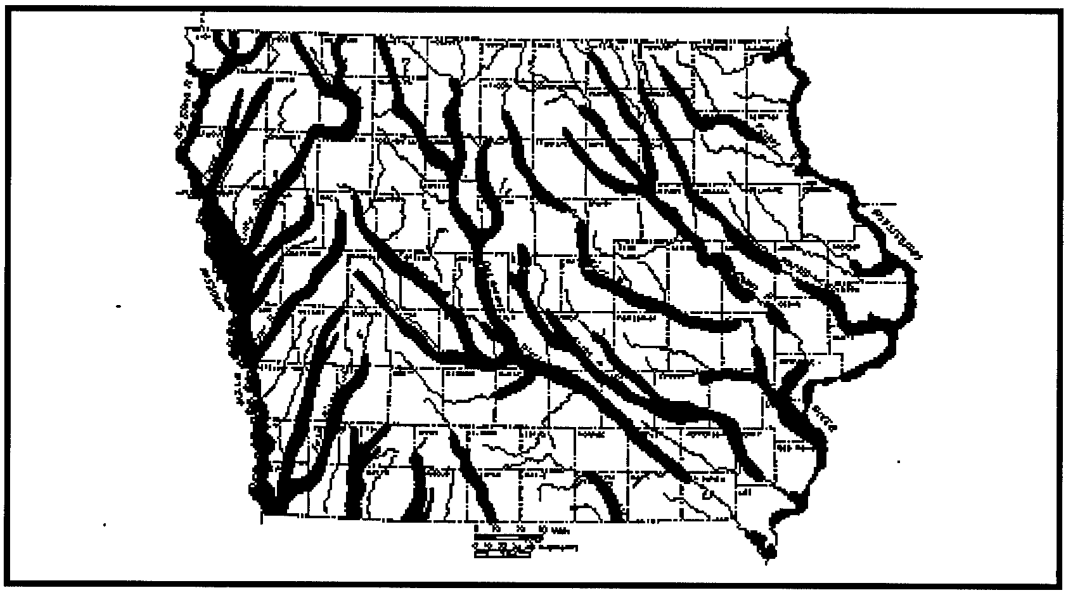


Figure 16. Principal alluvial aquifers of Iowa (Anderson 1983).

	AGE	ROCK UNIT	DESCRIPTION	HYDROGEOLOGIC UNIT	WATER-BEARING CHARACTERISTICS
Cenozoic	Quaternary	Alluvium Glacial drift (undifferentiated) Buried channel deposits	Sand, gravel, silt and clay Predominantly till containing scattered irregular bodies of sand and gravel Sand, gravel, silt and clay	Surficial aquifer	Fair to large yields Low yields Small to large yields
Mesozoic	Cretaceous	Colorado Group Dakota Group	Shale Sandstone and shale	Aquiclude Dakota aquifer	Does not yield water High to fair yields
Paleozoic	Pennsylvanian	Virgilian Series Missourian Series Des Moinesian Series	Shale and limestone Shale; sandstones, mostly thin	Aquiclude	Low yields only from limestone and sandstone
	Mississippian	Meramecian Series Osagean Series Kinderhookian Series	Limestone, sandy Limestone and dolomite, cherty Limestone, oolitic, and dolomite, cherty	Mississippian aquifer	Fair to low yields
	Devonian	Maple Mill Shale Sheffield Formation Lime Creek Formation	Shale; limestone in lower part	Devonian aquiclude	Does not yield water
		Cedar Valley Limestone Wapsipinicon Formation	Limestone and dolomite; contains evaporites in southern half of Iowa	Silurian-Devonian aquifer	High to fair yields
	Silurian	Niagaran Series Alexandrian Series	Dolomite, locally cherty		
	Ordovician	Maquoketa Formation	Shale and dolomite	Maquoketa aquiclude	Does not yield water, except locally in northwest Iowa
		Galena Formation Decorah Formation Platteville Formation	Limestone and dolomite Limestone and thin shales; includes sandstone in SE Iowa	Minor aquifer Aquiclude	Low yields Generally does not yield water; fair yields locally in southeast Iowa
		St. Peter Sandstone Prairie du Chien Group	Sandstone Dolomite, sandy and cherty	Cambrian-Ordovician aquifer	Fair yields
	Cambrian	Jordan Sandstone	Sandstone		High yields
		St. Lawrence Formation Franconia Sandstone (Lone Rock)	Dolomite Sandstone and shale	Aquiclude (wedges out in northwest Iowa)	Does not yield water
		Dresbach Group Wonewoc Eau Claire Mt. Simon	Sandstone	Dresbach aquifer	High to low yields
	Precambrian	Sioux Quartzite Undifferentiated	Quartzite Coarse sandstones; crystalline rocks	Base of groundwater reservoir	Not known to yield water except at Manson disturbed area

Figure 17. Table of Iowa aquifer potentials.

These aquifers are primarily located along rivers and other major bodies of water. These aquifers were formed by the advance and retreat of glaciers forming these low lying areas for water to settle. However, of primary importance to the Kirkwood site is the extreme relative location of these aquifers to the earthen manure lagoons.

The Kirkwood lagoon is based on an outbreak of eroded loess soil. This soil is a relatively old material, with origins approximately 2 million years old. The complexity of this site is complicated by the fact that there are several layers of oxidized and unoxidized till at this site. The first layer of soil is the oxidized till. See Figure 18 for a picture of oxidized till at the Kirkwood Community College site. This material is usually orange/red in color since this material contains ferric or manganic hydroxide deposits. This material tends to have a higher hydraulic conductivity (1 x 10^{-4} centimeters/second) versus unoxidized clay

(reduced form) due to larger pore spaces. This causes a greater oxygen transfer. Unoxidized clay till is usually darker gray to blue in color. This material usually has hydraulic

Figure 18. Visible geology at the Kirkwood site near north anaerobic lagoon.

conductivities about four orders of magnitude lower than the oxidized layers, on the order of 10^{-8} cm/second. The impact of this type of geologic material will be discussed in the following sections.

The final geological aspect of the Kirkwood site deals with a phenomenon that doesn't happen often (if ever) in Iowa. This phenomenon is earthquakes. According to Anderson, several faults exist in Iowa, albeit inactive ones. See Figure 19 for the fault zones in Iowa. The fault zones could play a major role in lagoon seepage, if a seismic event should happen to occur in Iowa in the next decade. Although not likely, earth quakes have been felt in Iowa as recently as this century. "The Good Friday Earthquake that proved disastrous to Anchorage, Alaska, on March 27, 1965, produced a shock sufficient to knock out one of the six seismometers at Loras College in Dubuque out of service" (Anderson 1983).

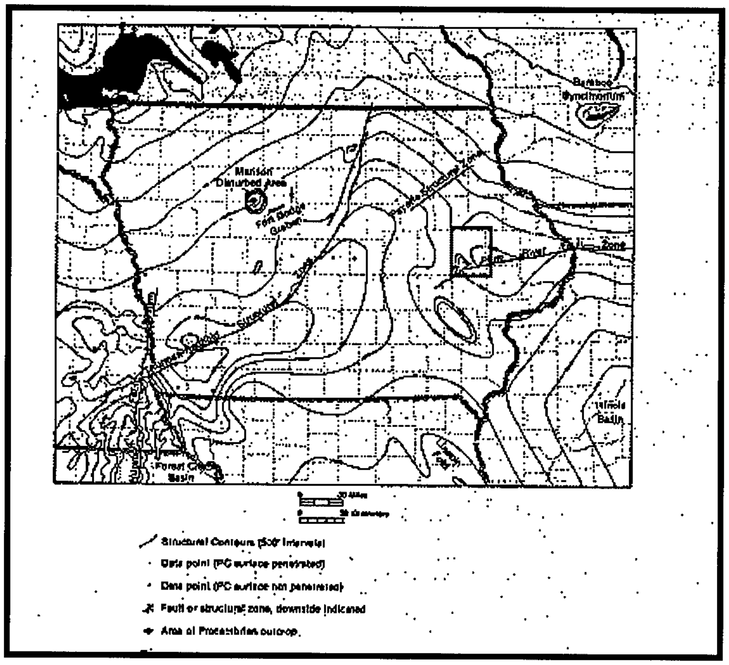


Figure 19. Iowa fault zones.

However, of primary importance to this study, is the Plum River fault which intercepts the general location of the Kirkwood lagoons in Linn County (highlighted in red). This may not pose a large threat, but California Civil Engineers would probably suggest constructing a lagoon on geo-membranes or some other form of synthetic liners to prevent catastrophic leakage during 'rare' (at least in Iowa) seismic events, such as earth quakes.

The advance and retreat of each glacial activity in Iowa helped form the complicated geologic foundation in existence today. This type of soil is generally well-suited for many types of engineering purposes, but hydrogeologic tests should be completed prior to any construction—especially projects like the Kirkwood lagoons that potentially endanger Iowa's groundwater resources.

Hydraulic Conductivity Analysis

Each soil type has differing geologic characteristics including density, grain size, and hydraulic conductivity. Hydraulic conductivity analysis is necessary in any groundwater monitoring project, such as the Kirkwood project. This type of testing can be performed using a slug test or some other technique. Pumping well tests, single auger hole hydraulic

conductivity tests, or methods which monitor drain outflow data in conjunction with mathematical modeling using the ellipse drainage equation to determine soil hydraulic conductivity, are all examples of other useful methods to determine hydraulic conductivity (Madramootoo et al. 1990).

A slug test is a way to change the water level in a well rapidly to measure the aquifer's response pattern to determine its hydraulic characteristics, namely hydraulic conductivity. A water 'extractor' and pressure transducer were used for this study, however other methods for recording water level rise exist (Downey et al. 1994). Several assumptions go in to hydraulic conductivity analysis depending on the type of analysis method chosen to reduce monitoring well data. Two slug tests for hydraulic conductivity were used in this report and compared: Bouwer and Rice and the Hvorslev slug test method. Both methods help delineate horizontal hydraulic conductivities at heterogeneous sites. Although not performed during this study, vertical hydraulic conductivities can also be calculated using methods such as those found in Butler (et al.) (1994).

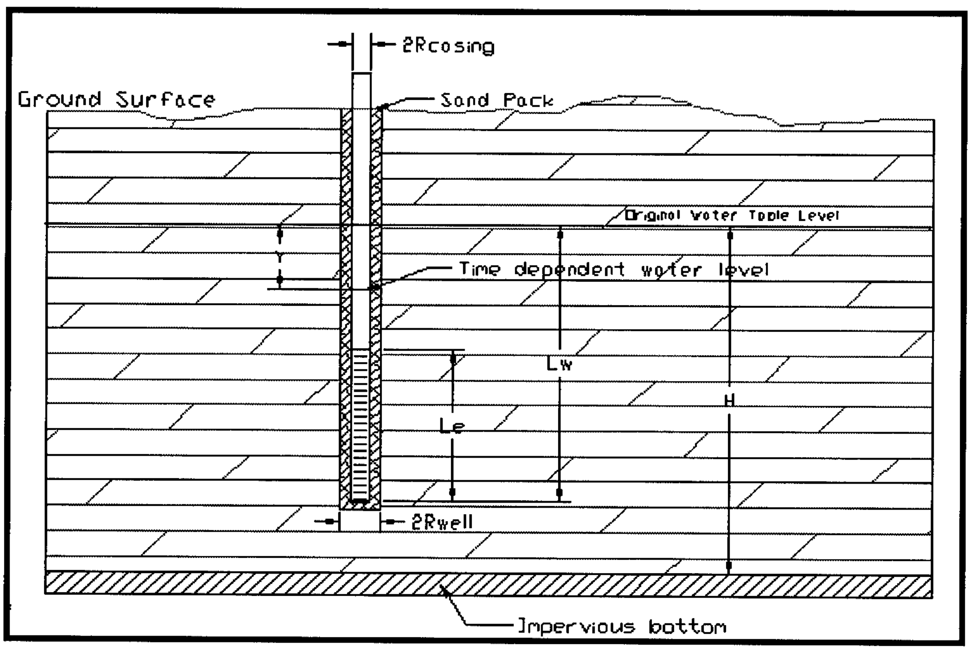


Figure 20. Bouwer and Rice slug test schematic.

The Bouwer and Rice slug test method is a simple and inexpensive test to perform. First, the operator measures the initial water level and depth to the bottom of the well prior to any other activities. This information is critical for a successful slug test. See Figure 20.

Next, the operator either raises or lowers the water level in the well quickly by either inserting a solid object (more dense than water) into the well or by withdrawing water rapidly out of the well. Finally, the operator measures the recovery of the well as it reaches

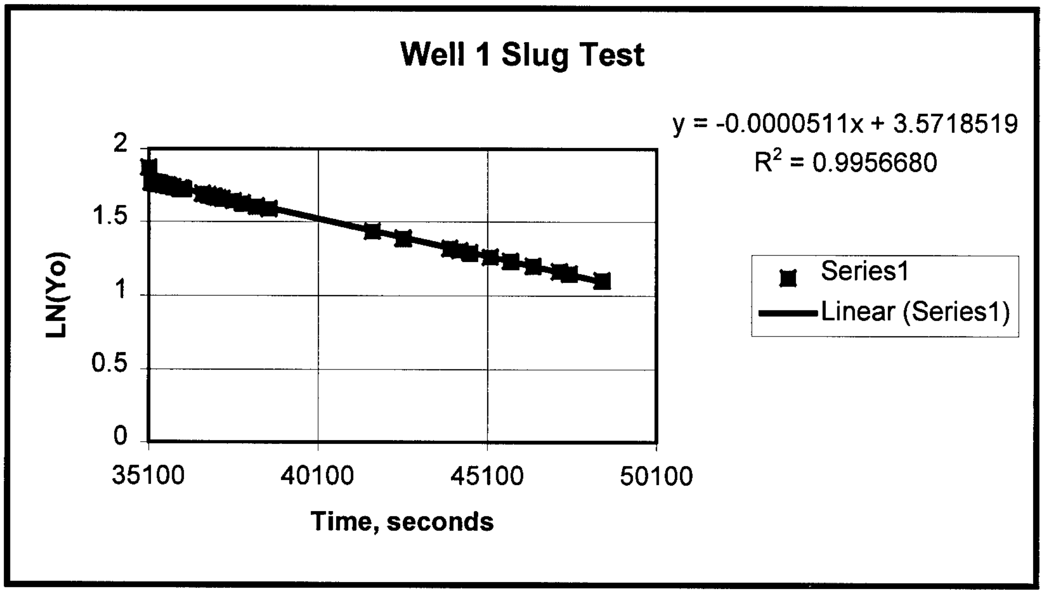


Figure 21. Example drawdown recovery graph.

equilibrium over time. The operator then transforms the drawdown (difference between initial water levels in the well and actual time-measured water levels in the well) data using a natural logarithm function plotted versus time to obtain the slope of the best-fit (linear regression) line. See Figure 21. The governing equation for the Bouwer and Rice hydraulic conductivity (K) is (Notes CE 573):

$$\boxed{K = \frac{-a \cdot Rc^2 \cdot \ln(\frac{Re}{Rwell})}{2 \cdot Le}}$$

Equation 1. Bouwer and Rice hydraulic conductivity equation.

where a = slope of regression line, R_c = radius of well casing, L_e = effective screen length, R_e = effective radius of well, and R_w = radius of well boring. This equation assumes an impervious boundary layer below the well, as well as a steady-state, unconfined aquifer presence.

However, the natural logarithm of the effective radius (R_e) divided by the radius for the well (R_{well}) is complicated and must be estimated. The two equations for the estimation of $\ln(R_e/R_{well})$ are:

Case 1: $L_w < H$

$$\boxed{\ln\frac{Re}{Rwell} = \left[\frac{1.1}{\ln(\frac{Lw}{Rwell})} + \frac{A + B\cdot\ln\left[\frac{(H-Lw)}{Rwell}\right]}{\frac{Le}{Rwell}}\right]^{-1}}$$

Equation 2. Bouwer and Rice--Case 1.

Case 2: $L_w = H$

$$\boxed{\ln\frac{Re}{Rwell} = \left[\frac{1.1}{\ln(\frac{Lw}{Rwell})} + \frac{C}{\frac{Le}{Rwell}}\right]^{-1}}$$

Equation 3. Bouwer and Rice--Case 2.

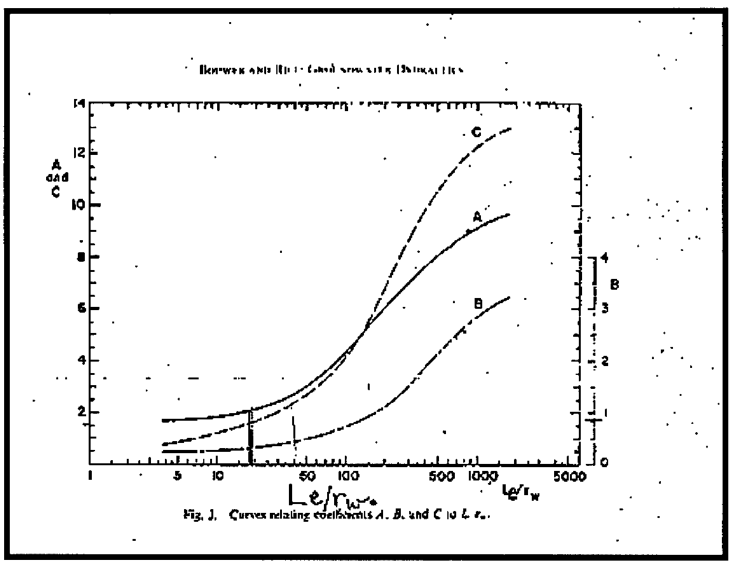


Figure 22. Bouwer and Rice coefficient curves (Bouwer and Rice 1976).

where A, B, and C are graphical coefficients derived by Bouwer and Rice (See Figure 22). If, however, L_e and L_w are equal, in other words, the well is screened at or above the water

table (i.e. partial penetration), then an additional substitution must be employed for a Bouwer-Rice slug test. In this case R_c is replaced with R_e where R_e is:

$$\boxed{\mathrm{Re}^2 = Rc^2 + n \cdot \left(Rwell^2 - Rc\right)}$$

Equation 4. Bouwer and Rice effective radius.

Once the regression slope is determined, careful application of the proper equation (using Equation 1, Equation 2, Equation 3, and/or Equation 4) yields the hydraulic conductivity (K) for the system in question.

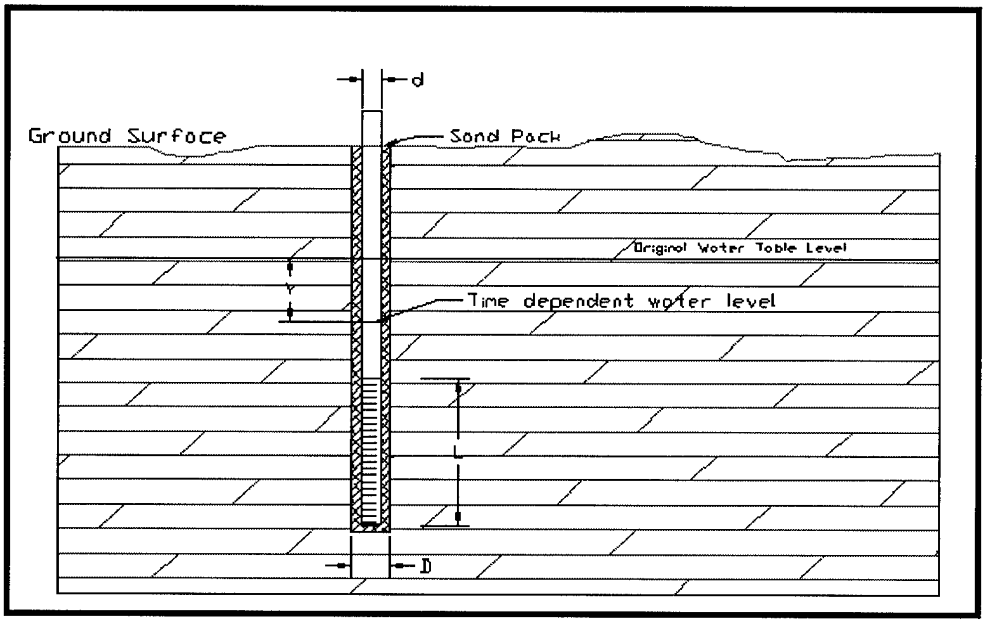


Figure 23. Hvorslev slug test schematic.

The Hvorslev slug test method (Figure 23) is performed in exactly the same manner as the Bouwer and Rice slug test, but is slightly easier to reduce the data and solve for the system's hydraulic conductivity. The governing equation for the Hvorslev hydraulic conductivity is:

$$\boxed{K = \frac{-a \cdot \pi \cdot d^2}{4 \cdot F}}$$

Equation 5. Hvorslev hydraulic conductivity equation.

where a = slope of the regression line, $\pi = 3.141593$, d^2 = radius of the casing, and F = shape factor for the particular well in question. The shape factors are based on closed form solutions to the Laplace equation, and account for various types of well geometry. The equation for the shape factor depends on the structure of the well. For a cylindrical injection zone:

Case 1: Pervious Bottom (L > D)

$$\boxed{F = \frac{2 \cdot \pi \cdot L}{\ln\left[\frac{L}{D} + \left[1 + \left(\frac{L}{D}\right)^2\right]^{0.5}\right]}}$$

Equation 6. Hvorslev--Case 1.

Case 2: Impervious Bottom

$$\boxed{F = \frac{2 \cdot \pi \cdot L}{\ln\left(\frac{2 \cdot L}{D}\right)} - 2.75 \cdot D}$$

Equation 7. Hvorslev--Case 2.

The biggest problem with using either the Bouwer and Rice or the Hvorslev slug test method is keeping consistent units throughout the entire procedure. Both methods require consistent units in order for the hydraulic conductivity solutions to work. Therefore, if drawdown readings are recorded in centimeters and time is recorded in minutes, then units for hydraulic conductivity (K) will be in centimeters per minute.

The Kirkwood site has very slow hydraulic conductivities. The complete listing of all slug test results is shown in Table 2. Appendix C contains raw data of drawdown (Y) versus time for monitoring wells one through five.

	Bouwer-Rice Slug Test Method		**Hvorslev Slug Test Method**	
Monitoring Well Description	Hydraulic Conductivity, feet/second	Hydraulic Conductivity, centimeters /second	Hydraulic Conductivity, feet/second	Hydraulic Conductivity, centimeters /second
Well 1	7.351×10^{-8}	2.241×10^{-6}	8.001×10^{-8}	2.441×10^{-6}
Well 2	3.235×10^{-7}	9.859×10^{-6}	4.188×10^{-7}	1.277×10^{-5}
Well 3:				
a (initial slope)	5.607×10^{-6}	1.709×10^{-4}	7.116×10^{-6}	2.169×10^{-4}
b (final slope)	4.506×10^{-6}	1.373×10^{-4}	5.718×10^{-6}	1.743×10^{-4}
Well 4 *(Partial Penetration)*	6.222×10^{-8}	1.896×10^{-6}	8.120×10^{-8}	2.475×10^{-6}
Well 5	1.597×10^{-8}	4.867×10^{-7}	1.959×10^{-8}	5.972×10^{-7}

Table 2. Hydraulic Conductivity—Results of Slug Tests.

Hydraulic conductivities were highest in the general vicinity of monitoring well's # 2 through #4, located on the east bank of the anaerobic lagoon (north lagoon). High conductivities in such a close proximity to the anaerobic lagoon is a potential hazard for both groundwater and surface water quality. This hazard is amplified due to the local groundwater flow pattern which funnels contaminants towards the areas of highest hydraulic conductivities. Higher hydraulic conductivities will lead to faster response and travel times of accompanying contaminants. This will be discussed in greater detail in following sections. See Figure 24 for a three-dimensional representation of the hydraulic conductivities located at the Kirkwood site.

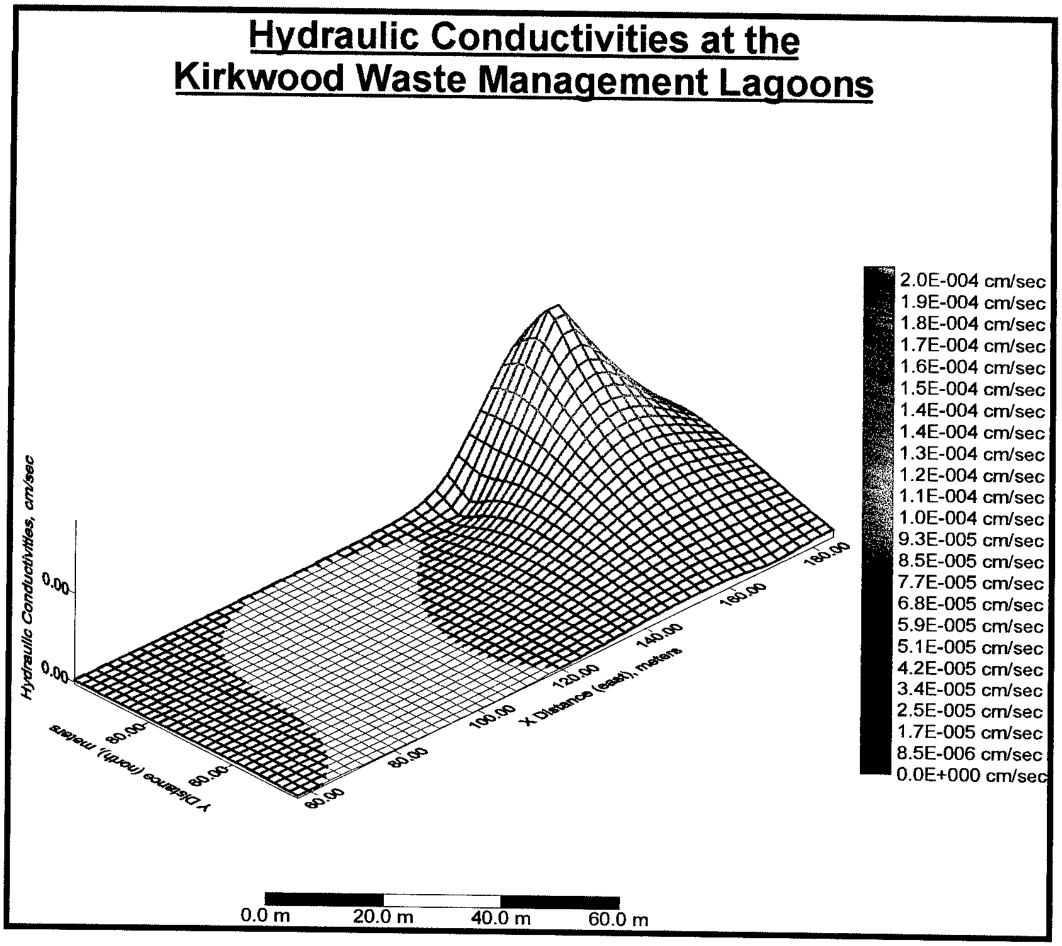


Figure 24. "Surfer 6.0" hydraulic conductivity plot.

The two slug test methods, Bouwer and Rice and Hvorslev, provide similar hydraulic conductivities for the same test run. However, Hvorslev hydraulic conductivities are slightly higher than the Bouwer-Rice results (approximately 25% higher). For this study, the average Hvorslev hydraulic conductivities from MW3 (2.0×10^{-4} cm/sec) were selected for use in engineering analysis and contaminant transport equations to provide the "worst case" scenario for contaminant transport, i.e. the fastest transport possible using the highest hydraulic conductivities.

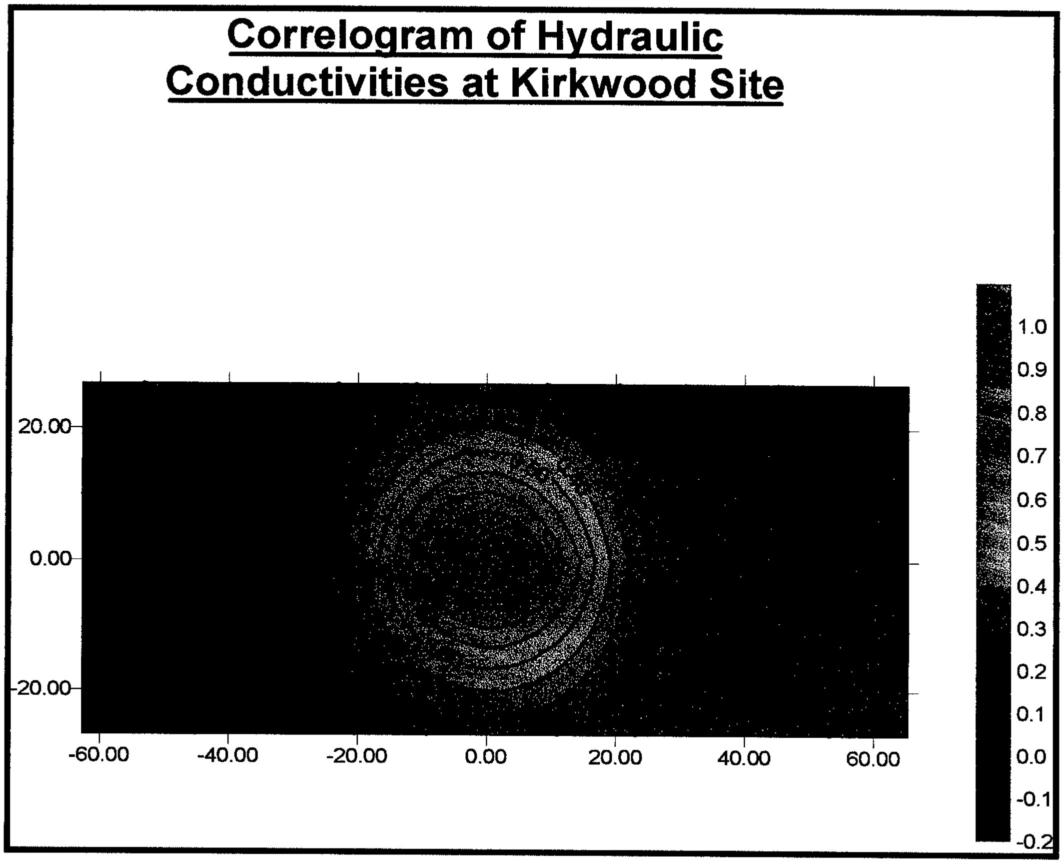


Figure 25. "Surfer 6.0" spatial correlation of hydraulic conductivities at Kirkwood site.

Hydraulic conductivities at the Kirkwood lagoons are not homogeneous--a typical feature of most field studies. See Figure 25 for a spatial correlation (anisotropy diagram) of hydraulic conductivities at the site. This graphic demonstrates that the only place with a perfect correlation of hydraulic conductivity values occurs where no slug tests were taken—under the lagoons themselves. Thus, low correlation values between hydraulic conductivities at each well indicates a heterogeneous soil system. This will be important in contaminant transport assumptions and calculations.

The Bouwer and Rice slug test method is based on steady state flow assumptions with intended use in unconfined aquifers, although work by Bouwer (1989) has been done to apply this method to confined aquifers as well. Several key assumptions are applicable to the unconfined aquifer case. First, drawdown of the water table around the well can be ignored. Second, flow in the unsaturated zone (including the capillary fringe) is negligible. Third, hydraulically, the well is 100% efficient. Finally, the aquifer is homogeneous and isotropic

(Brown et al. 1995). The Kirkwood aquifer is not isotropic, but for this study isotropic conditions are assumed. The Bouwer and Rice method is based on the Theim (1906) equation which relates flow rate to drawdown and hydraulic conductivity in a radial system. Theim's equation is:

$$\boxed{Q = 2 \cdot \pi \cdot K \cdot L \cdot \frac{y}{\ln(\frac{\mathrm{Re}}{Rwell})}}$$

Equation 8. Theim equation.

where Q is the volumetric flow into the well, K is the hydraulic conductivity, L is the screen length, y is the head change in the well, R_e is the "effective radius over which y is dissipated" (Bouwer and Rice 1976), and R_{well} is the borehole radius. If one looks at one 'slice' in time the rate of flow into the well is:

$$\boxed{\frac{dy}{dt} = \frac{-Q}{\pi \cdot {r_c}^2}}$$

Equation 9. Time derivative of flow.

"By combining (8) and (9), we essentially get a description of a radial flow permeameter, with inner area = 2*Pi*R_{well}*L, outer area = 2*Pi*R_e*L, and flow length = (R_e-R_{well}). Together, equations (8) and (9) lead to the equation (1)" (Brown et al. 1995). According to an evaluation of the Bouwer and Rice slug test method by Brown (et al.), "in general, the Bouwer and Rice method tends to underestimate the hydraulic conductivity, with the greatest errors occurring in the presence of a damaged zone around the well or when the top of the screen is close to the water table" (Brown et al. 1995). This scenario would be similar to wells approaching partial penetration situations. Thus, the Hvorslev conductivity results were used in contaminant transport calculations to ensure a "worst-case" scenario of chemical transport and to prevent an underestimation of slug test results.

The Hvorslev slug test method is a basic time lag method. This method uses shape factors to estimate hydraulic conductivities whereas the Bouwer and Rice method uses shape coefficients derived from an electric analog experiment to determine shape factors. Hvorslev

followed a different path than Bouwer and Rice to solve for his method's shape factor. "Hvorslev relied entirely on approximating analytical solutions developed by previous researchers for the various geometrical configurations to determine the shape factor" (Brown et al. 1995). Bouwer and Rice based their method on actual testing in the field using the electric analog. This contributes significantly to the success of the Bouwer and Rice slug test methods when compared to known soil hydraulic conductivities. "The fact that the method provides reasonable estimates of hydraulic conductivity suggests that the empirical, electric analog experiments of Bouwer and Rice have yielded shape factors that are better than the shape factors implicit in the Hvorslev method" (Brown et al. 1995). However, both methods provide only an 'order of magnitude' estimate of the in situ hydraulic conductivity due to the extreme heterogeneity of the site. This heterogeneous nature would allow different conductivities to be calculated if the exact same well was tested twice, once right after another slug test. These diverse geologic characteristics make contaminant transport modeling difficult to predict.

Soil/Till Flow Pathways

The United States Department of Agriculture regularly publishes a complete soil description for all the counties in Iowa, as well as other states. This soil survey tells important information about the soil series and classifications prominent in that area, and also provides some basic engineering guidelines about construction properties. There are several different soil types at the Kirkwood lagoon site. See Table 3 for a complete description of the soils important to the Kirkwood site.

Soil Type	Classification Name	Soil Description	Parent Material	Slopes, %	Erosion Potential	Maximum Dry Density, lbs/ft^3	Depth to Bedrock, ft
Kenyon-1	83B	loam	Loamy erosional sediment and glacial till	2-5	-	0"-8" = 106; 29"-35" = 112; 55"-74" = 118	>10
Kenyon-2	83C2	loam	Loamy erosional sediment and glacial till	5-9	moderate	0"-8" = 106; 29"-35" = 112; 55"-74" = 118	>10

Soil Type	Relative Permeability, in/hr	Available Water Capacity, in/in-soil	pH	Depth to Seasonal High Water Table, ft	Soil Limitations for Sewage Lagoons	Organic Content
Kenyon-1	0"-"17" = 0.63-2; 17"-52" =0.2-0.63; 52"-67" = 0.2-0.63	0.17-0.19; 0.15-0.18; 0.15-0.18	5.6-7.3; 5.1-6.0; 6.6-7.3	-	Moderate (occasional sand pockets)	High
Kenyon-2	0"-"17" = 0.63-2; 17"-52" =0.2-0.63; 52"-67" = 0.2-0.63	0.17-0.19; 0.15-0.18; 0.15-0.18	5.6-7.3; 5.1-6.0; 6.6-7.3	-	Moderate (occasional sand pockets)	High

(Schermerhorn and Highland 1971)

Table 3. Principle soil types at Kirkwood lagoon site.

The soil types at the Kirkwood site demonstrate a relatively high chance for lagoon seepage based on the present soil types (Kenyon 83B and 83C2) under the lagoons. However, if the lagoon is lined with clay and compacted to near maximum density, the chance of seepage greatly decreases as the lagoon "seals" itself, as reported in the literature (Sewell 1978; Ciravolo et al. 1979; and Quade and Libra 1995). The following schematic depicts the general topography for the soils primarily found at the Kirkwood site.

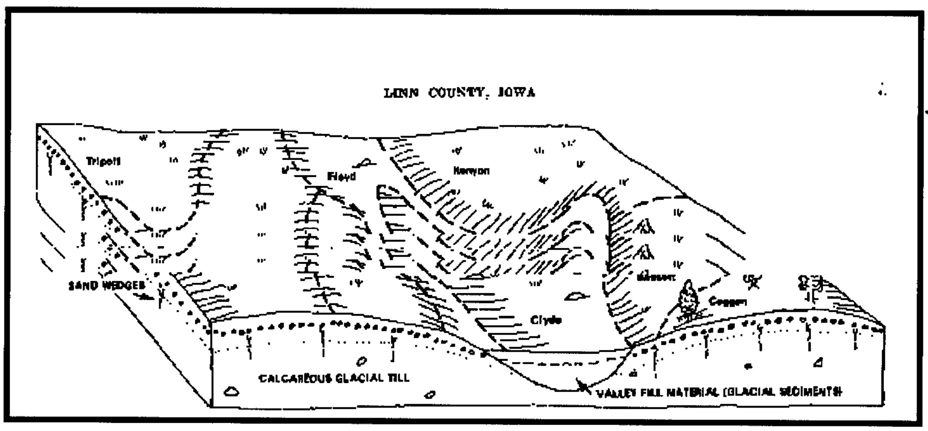


Figure 26. USDA schematic of Kenyon-Clyde-Floyd association (Schermerhorn and Highland 1971).

This schematic demonstrates the relationship between the glacial till and other important features affecting the hydraulic conductivities of this site. Notice the sand wedges and calcareous glacial till material immediately underlying the most prominent soil types located at the Kirkwood site. (See Figure 27 for soil types at Kirkwood site.) These unique

soil features will impact contaminant transport and groundwater quality by increasing travel speeds of contaminants through sand lenses and fractures.

As seen in Figure 27, two extreme deposits of sand exist at the Kirkwood site. The west spot is approximately located around Monitoring Well #3, at the base of the north manure lagoon. There is support for this evidence in the hydraulic conductivity analysis, as discussed earlier. Monitoring Well #3 had the highest hydraulic conductivities at the Kirkwood lagoon site. This extremely high hydraulic conductivity situated directly down-gradient of the north lagoon poses a potential hazard to groundwater quality. According to the USDA soil survey, the soils at the Kirkwood site are only "moderately" suitable for construction of a sewage lagoon. The soil survey states "'moderate' means that some of the soil properties are unfavorable but can be overcome or modified by special planning and design" (Schermerhorn and Highland 1971). However, at the Kirkwood lagoon, no additional planning or design measures (like clay liners, synthetic liners, etc.) were

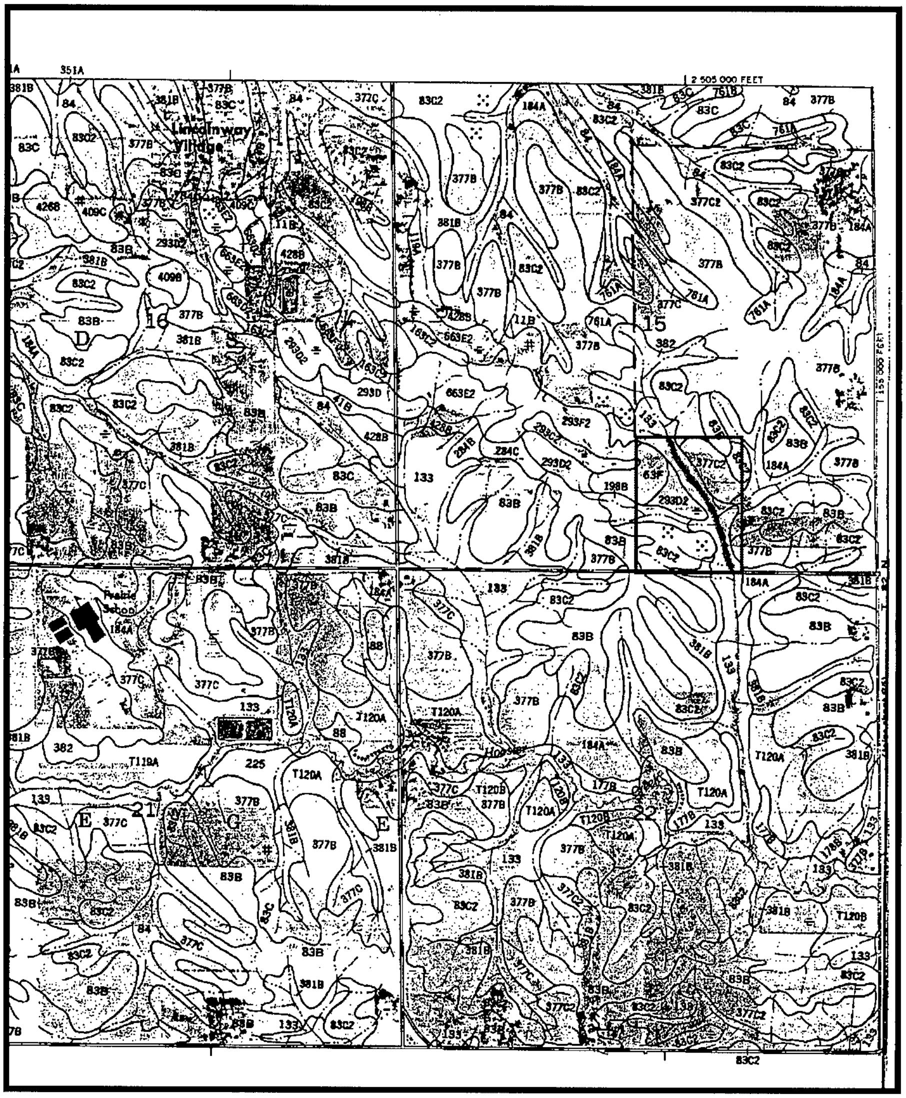


Figure 27. USDA soil survey map of the Kirkwood site (Schermerhorn and Highland 1971).

developed or activated. Based on the USDA soil survey, the Kirkwood location would be a poor choice for an unlined swine waste lagoon. Alternate flow paths such as sand pockets or lenses could cause short-circuiting and accelerated groundwater flow conditions. Ultimately, the amount of leakage from the lagoons and related damage to water quality will be driven by the amount of sealing in the lagoon and the effective porosity of the surrounding soil environment. Nevertheless, based on hydraulic conductivity measurements taken at MW4 (located on the down-gradient side and edge of the lagoon), the lagoon appears to be constructed on clay, and not on one of the underlying pockets of sand. Therefore, seepage

from the lagoon should be minor and pose little environmental hazard to the surrounding water resources.

Seepage from the Lagoons

Several authors have reported lagoon's 'sealing' action after the initial animal waste loading. This sealing process is thought to be attributed to either physical, biological, or chemical processes (Chang et al. 1974; DeTar 1979). Physical processes arise from the actual soil particles becoming plugged with animal waste solids, thus restricting seepage through the lagoon floor. In most documented cases, seepage occurred in consolidated places surrounding the lagoon in question. Westerman, Huffman, and Feng noted a "large variability between locations and wells, indicating that seepage is very localized. Thus, location of monitoring wells must be extensive enough to detect localized seepage" (Westerman et al. 1995). Seepage areas similar to the ones noted on the north side of the Kirkwood anaerobic lagoon were also described in a study by Huffman and Westerman on lagoons in the North Carolina coastal plain. The reason for this seepage is primarily attributed to the high head differentials between the lagoon liquid level and the groundwater level of the surrounding aquifer.

Research has been done on this sealing process that occurs in lagoons to determine the actual time periods required to adequately seal a lagoon to prevent seepage discharges above regulatory levels. According to Huffman and Westerman, "natural clogging of the soil pores can greatly reduce seepage loss rate, but will not eliminate losses completely" (1995). They proposed that the major factor determining lagoon seepage loss seemed to be the type of materials used in construction of the lagoon. Clays will seal materials better due to the small particle size ($< 2\ \mu m$), which can act as a "straining mechanism" for biological particles or solid waste material. Clays also possess the ability to exchange ions with other chemical species in the soil/aquifer system. This plays an important role in concentrations measured at the Kirkwood site, which will be discussed later.

Seepage can be modeled in both two and three dimensions. Using the Dupuit-Forchheimer assumptions, an approximate solution can be developed. The 2-D approximate seepage equation is:

$$\boxed{Q_L = \frac{Ks}{2 \cdot W} \cdot (H_p{}^2 - H_s{}^2)}$$

Equation 10. 2-D seepage flow rate from lagoon.

where Q_L is the flow rate per unit length of lagoon ($m^3/m*hr$), and H_p and H_s are water levels in the pond and sink expressed in terms of total hydraulic head (m). This equation neglects unsaturated flow and head loss due to vertical flow near the source and sink (Fipps and Skaggs 1990). Thus, the equation for radial flow in the region of the pond is:

$$\boxed{Q = 2 \cdot \pi \cdot K_s \cdot H_{avg} \cdot \frac{H_p - H_R}{\ln(\frac{R}{r})}}$$

Equation 11. Lagoon radial flow.

where $H_{avg} = (H_p - H_R)/2$, the average flow depth; $(H_p - H_R)$ is the head drop in the radial flow region; r is the radius of the pond, taken as $r = W_p$ (width of pond) $= L_p$ (length of pond) and R is the horizontal extent of the radial flow region which can be estimated as:

$$\boxed{R = L_p + \frac{L}{2}}$$

Equation 12. Radius of seepage flow.

For the region of 2-D flow, Equation 10 is used in the form of:

$$\boxed{Q = \frac{K_s \cdot (L + L_p)}{2 \cdot W_e}(H_R{}^2 - H_S{}^2)}$$

Equation 13. 2-D flow equation for seepage.

where H_R is the head at the radial distance R or at $x = W_e$; and W_e is the effective width of the linear flow region, approximated as:

$$\boxed{W_e = W + W_p - R \cdot \cos\alpha}$$

Equation 14. Effective width of linear flow region.

Equating Equation 11 and Equation 13 yields the approximate solution for pond seepage:

$$\boxed{Q = \frac{K_s \cdot L_e}{2 \cdot W_e}(H_p{}^2 - H_s{}^2)}$$

Equation 15 → Valid for $W_e > 0$

Equation 15. 3-D pond seepage equation.

where L_e is:

$$\boxed{L_e = \frac{L + L_p}{1 + \left(\frac{2 \cdot (L + L_p)}{W_e \cdot \pi}\right) \cdot Ln(\frac{R}{L_p})}}$$

Equation 16. Seepage effective length.

However, the critical issue is the total magnitude of seepage losses in comparison to local groundwater flow. In one study, researchers noted that "although contaminant concentrations in the seepage are far above water quality standards, small amounts of seepage can be assimilated or diluted to harmless concentrations" (Huffman and Westerman 1995). Although early researchers felt unlined lagoons posed little or no threat to the environment due to this dilution effect with groundwater, current literature suggests more stringent controls on such discharges.

According to Ritter (et al.), an unlined anaerobic two-stage swine waste lagoon will "not have a serious impact on groundwater quality," but Ritter (et al.) also states in the same report that "all lagoons installed in loamy sand or sandy loam soils on the Delmarva Peninsula should have a clay liner to protect groundwater quality" (1984). Additional evidence of this recent shift in engineering theology about swine waste lagoons is evident in the March/April 1995 WRRI news bulletin. This report states "North Carolina State University researchers found evidence that more than half of older, unlined swine waste

lagoons in eastern North Carolina are probably leaking high concentrations of nutrients, primarily nitrogen, into shallow groundwater" (1995). The report goes on to discuss further impacts of lagoons on surface water quality in the surrounding region. The researchers concluded from their study that "while some sealing of swine lagoons may take place in sandy soils, the sealing is not always adequate to restrict seepage to acceptable levels" (WRRI 1995). Lagoon sealing may not be adequate, or worst case, non-existent in several Iowa swine waste lagoons—possibly including the Kirkwood site.

The Kirkwood lagoons are seeping. This is clearly evident by the increasing chloride concentrations in the down gradient monitoring wells. However, as determined by the 2-D and 3-D seepage equations (See Appendix D), less than 4 liters of lagoon liquid (<1 gallon) is seeping out of the lagoons per day. This is less than 1% of the Iowa regulatory standard for lagoon seepage. Since the apparent lagoon seepage rate is slow, little impact will be felt by this relatively new lagoon structure on surrounding water resources.

WATER QUALITY

Local Groundwater Flow Patterns

The local groundwater flow pattern at the Kirkwood lagoon site follows the general topography of the soil formations above it. The aquifer travel direction is primarily north-east, towards the adjoining creek. See Figure 28.

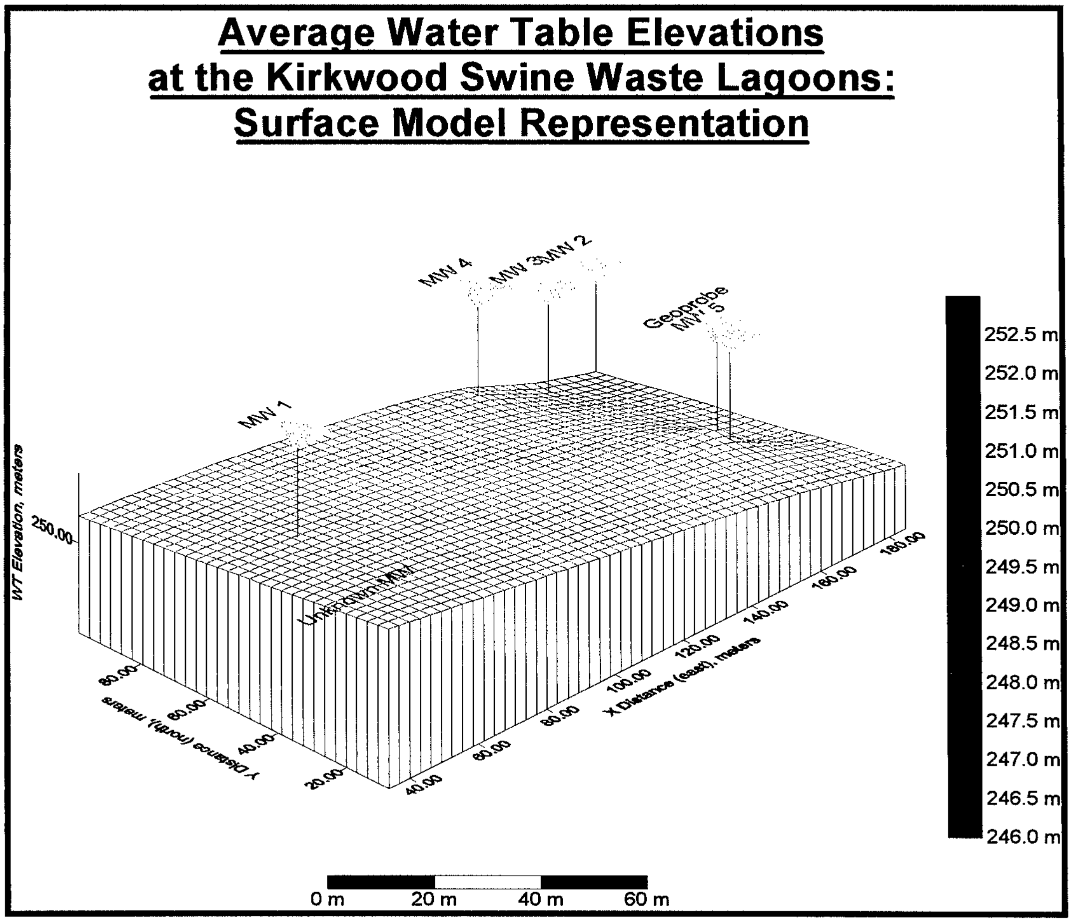


Figure 28. Water table elevations at the Kirkwood site.

The water table elevations were measured at various times throughout the year and as previously discussed, averaged to provide a "moderate" value for the actual water table elevation. Although actual water table elevations may vary with each passing season, the general direction of flow was assumed to be relatively constant.

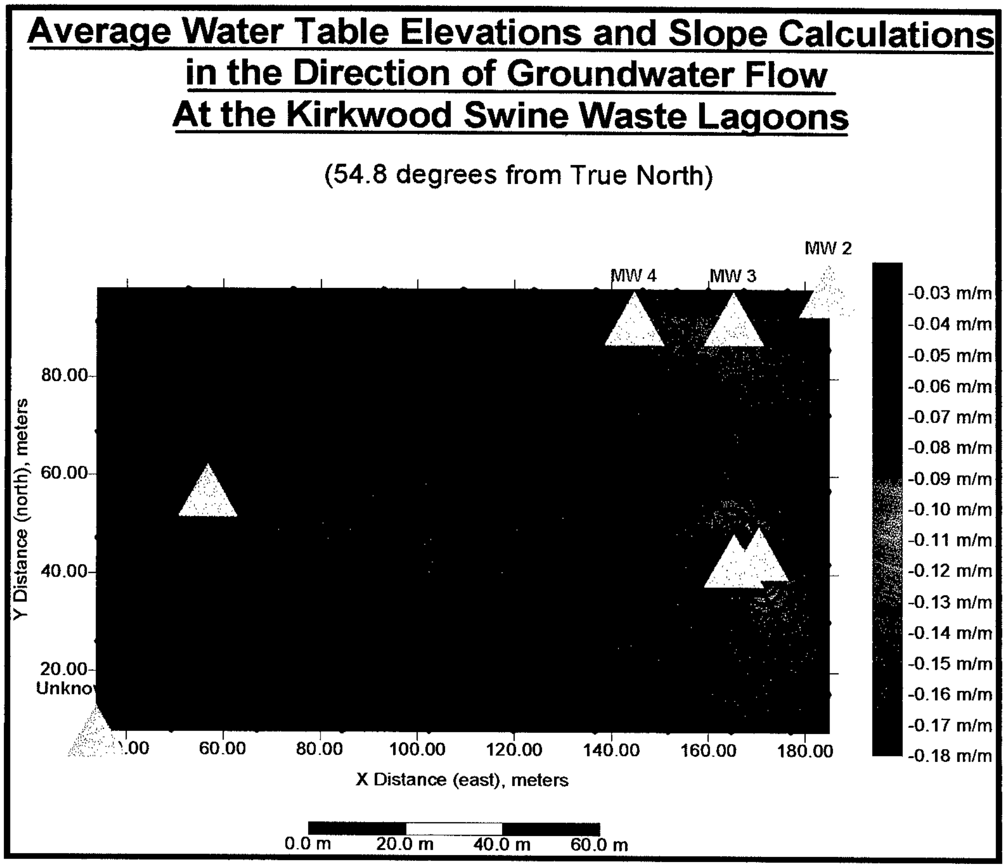


Figure 29. "Surfer 6.0" water table elevations and gradients.

High hydraulic head differentials contribute to high hydraulic gradients between lagoon the liquid and groundwater. Hydraulic gradients as high as 1% based on water table elevations were noted by Westerman (et al.). Seepage from this type of lagoon environment has been shown to occur in recent literature studies. The average water table slope for all the nodes contained in the Kirkwood grid file for "Surfer 6.0" was 4.18% at an angle of 54.8° measured clock-wise from true north (360°). However, the calculated water table gradient in the direction of groundwater flow was 0.092 % (approximately equal to those reported in the literature), based on statistical calculations (See Appendix H) at the 95% confidence interval. The average water table slope was used in this report to simulate the worst possible transport scenario (i.e. fastest chemical velocities through aquifer), since it is almost 50 times larger than the computed 95% confidence level gradient. See Figure 29 for water table elevations and gradients at the Kirkwood site. See Table 4 and Table 5 for flow direction and slope

data. The water table gradient is measured in units meters of elevation rise per meter of longitudinal distance and is based on the average measured water table elevations taken at the Kirkwood lagoon. High water table gradients in the immediate vicinity of the lagoons pose a hazard as it makes groundwater transport easier and more pronounced than studies with less gradient.

Statistical Analysis of Groundwater Flow Direction
Angles based on Average Water Table Data

PARAMETER DESCRIPTION	VALUE
Number of numeric cells	*1344*
Sum	*410122.6*
Average Flow Direction Angle	*305.1508*
Standard Deviation	*10.4236*
Minimum	*263.3438*
Maximum	*327.7846*

Table 4. Statistical analysis of water table flow directions.

The grid nodes for "Surfer 6.0" were formulated using a Kriging method to interpolate between unknown and known average water table elevations. The average water table was used to estimate the head and gradient of groundwater flow. Fluctuating water tables cause a 'smearing' of contaminants both vertically and horizontally within an aquifer. This causes contamination plumes to form and is the result of changing water table gradients as well as flow directions for various climatic seasons. For this study, average water table readings for all five monitoring wells were assumed to be representative of equilibrium aquifer conditions.

Statistic Analysis of Groundwater Gradients Based on General Flow Direction

PARAMETER DESCRIPTION	VALUE
Number of numeric cells	*1344*
Sum	*-56.19563*
Average Water Table Slope	*-4.181223E-2*
Slope Standard Deviation	*0.0172378*
Minimum Slope	*-0.188211*
Maximum Slope	*-0.0265015*

Table 5. Statistical analysis of water table slope in principle flow direction.

As seen in Figure 30, the actual groundwater flow intercepts both lagoons and proceeds in a line parallel to the axis of monitoring wells two through four. Therefore,

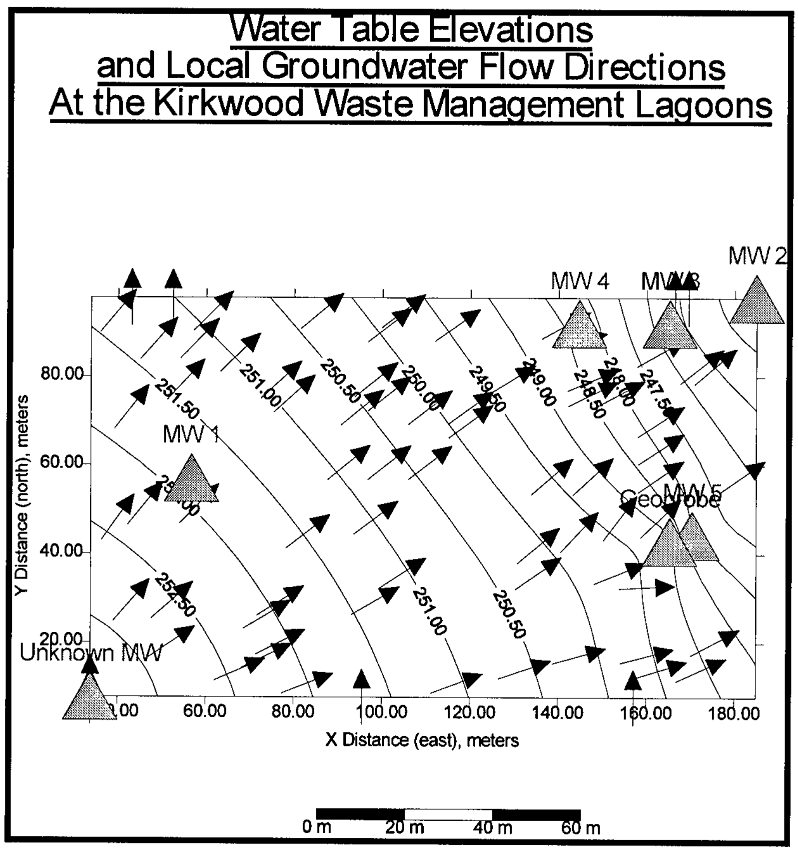


Figure 30. Groundwater flow directions at Kirkwood site.

contaminant concentrations should decrease from the highest levels in MW4 to the lowest levels in MW2, the farthest well from the source and also in the general groundwater flow direction. This concentration decrease is caused by the chemicals mixing with the aquifer and ultimately being diluted as they travel away from the lagoons with the groundwater. As calculated in Appendix H, the dispersivity (1.25 m) of the Kirkwood site is within the range typically found in the field (0.1-2.0 m) (Geology 534 notes). The large Peclet number for this system (162) also indicates an advection-dispersion flow regime for the system, with diffusion not being a key player in contaminant transport for the Kirkwood site.

Regional Groundwater Flow Patterns

No real estimate of regional groundwater flow patterns was made in this study. However, to adequately assess the impact of this lagoon on surrounding communities and homesteads, a more complete water table study should be performed to determine the impact of these lagoons on water quality in areas removed from the immediate vicinity of the Kirkwood lagoon site.

Surface Water Quality

The lagoons' impact on surface water quality was also studied in this report. The water quality characteristics in the neighboring Kirkwood stream are contributed by groundwater recharge, subsurface tile-line flow, and surface runoff infiltration. The small creek that lies adjacent to the Kirkwood lagoons is primarily fed by subsurface sources, specifically a small clay tile-line. Orientation of the creek is north/south, being located approximately 202 meters (660 feet) east of the eastern side of the lagoons. See Figure 31 for a picture of the creek that drains the basin near the Kirkwood lagoons.

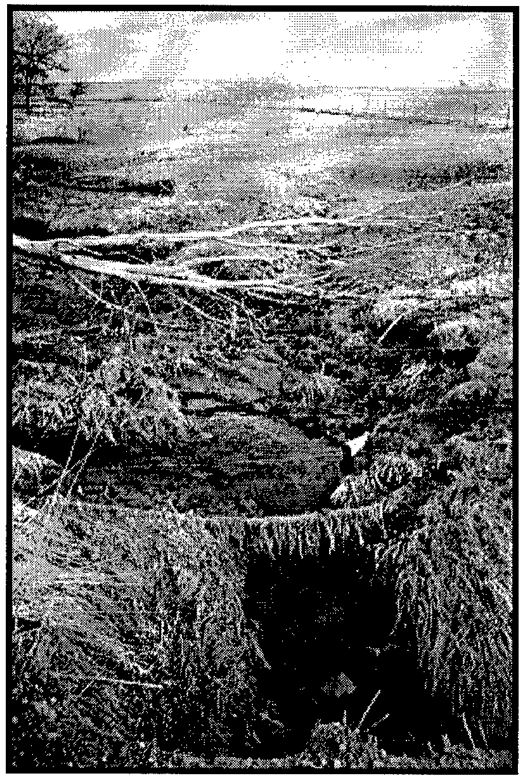


Figure 31. Creek at Kirkwood Community College lagoon site.

As previously stated, the creek originates from two subsurface tile-line outlets. The first tile outlet discharges approximately 1.2 m north of the north Kirkwood pasture fence line. However, upon inspection on May 15, 1997, there was no discharge from this source. The creek-bed was damp, but there was no running water in the creek at the northern edge of the pasture. The northern boundary to the Kirkwood creek had a width less than one foot (0.3048 m) wide and an average depth of three inches (7.62 cm). The primary surface water source for this creek is a subsurface tile-line discharge south of the north fence line. Although there are large surface areas draining into this watershed, which could contribute to the water in the creek, additional farming practices from surrounding row-crop fields probably play a more important role in the creek's water quality than do the Kirkwood lagoons. In summary, the main subsurface source appears to be the broken tile-line outlet found about straight east of the Kirkwood lagoon site.

The source of the creek is a 10.16 cm (four-inch) clay drain tile-line that is cracked and ruptured about midway down the creek, approximately 46 meters (150 feet) south of the

north pasture fence line. The tile-line outlet is directly east and down-gradient from the Kirkwood lagoon Monitoring Wells 2, 3, and 4.

This tile-outlet appears to be installed around 1950 or before, based on the composition of the tile. Fired-clay is not commonly used today due to the substitution of corrugated plastic drain tile. Therefore, this tile-line was probably installed several years before the lagoon was even designed or constructed. Above this point, there is no water entering the creek, except for this tile-line. Subsurface flow is ultimately the source for this surface water system.

The total flow for this stream was estimated using the Manning equation for fluid flow and assuming only subsurface flow contributed to the stream. "The Manning equation relates average stream velocity directly to the channel bed slope and hydraulic radius and inversely to a channel roughness coefficient": (Thomann and Mueller 1987)

$$\boxed{Q = \frac{1.0}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2}}$$

Equation 17. Manning equation.

where Q is the flow rate in m^3/second; n is the Manning roughness coefficient; A is the flow cross-section area in m^2; R is the hydraulic radius of the cross-section in m (assumed—full pipe flow); and S is the slope of the channel or pipe in m/m. The pipe flow rate was calculated using a pipe diameter of 0.1016 m (4 inches), a slope of 0.04 m/m (based on USGS topographic map), and roughness coefficient of 0.012 for clay (4 inch diameter) tile-lines (Iowa Drainage Guide 1987). The total flow entering the stream is 1.17×10^{-2} m^3/sec or 0.4135 cfs. See Appendix E for surface water calculations.

The tile-line source, with a background pH of four, provides a significant flow volume—the tile-line was running full when inspected in 1997. Although the Iowa DNR has not monitored or sampled this stream since the beginning of the lagoon project, ammonia-nitrogen, pH, and chloride determinations were all performed during this study on the north and south boundaries for the Kirkwood stream. The data collected for this report is not statistically relevant, however, since only one sampling set was performed (one sample and

one duplicate). Nonetheless, these three tests do provide some qualitative indication of stream quality.

An acidic pH will prevent nitrifying bacteria's conversion ability of ammonia-N into nitrate-N. According to Thomann and Mueller, "the alkaline environment is required to neutralize the acidic end products. Below a pH of 6.0, inhibition occurs" (1987). Thus, ammonia levels in the creek should not be lowered by nitrification processes. However, ammonia levels will probably decrease in the creek since it is a volatile compound. Ammonia doesn't stay dissolved in water, but prefers to diffuse to the atmosphere instead.

Ammonia samples from the Kirkwood creek were also taken to the ISU Toxicology laboratory for sampling. The creek had less than 0.5 mg/L ammonia-N concentrations. Ammonia-nitrogen was determined for the adjoining stream system at the Kirkwood site based on the methods described in "Ammonia in Blood, Urine, and Rumen Fluid: Microdiffusion Method" (Stahr 1991). Total ammonia levels were equal to or less than 0.5 mg/L in the stream at both the northern and southern Kirkwood pasture boundaries. See Appendix F for ammonia-nitrogen calculations.

Chloride levels were determined using a turbidimetric analysis procedure as defined in (Stahr 1991). See Appendix G for complete chloride laboratory results. The south creek had chloride levels approaching 24 mg/L (at the 95 % confidence interval), while the north creek sample had concentrations below 9 mg/L (at the 95 % confidence interval). This indicates increasing chloride levels either due to lagoon recharge or to surface water runoff in the immediate area. Another indicator of seepage is found in the chloride levels from the north stream tile-line sample. This sample had chloride concentrations about half (12 mg/L at the 95 % confidence interval) those of the south creek. Chloride levels are increasing rapidly as water flows downstream. However, since only one complete replicate was performed, this data can only be used as an indicator of water quality—not for confirmation purposes.

Probably the biggest potential health hazard in the stream, although not monitored in this study, was in the form of nitrate-nitrogen. This anion causes "blue-baby" syndrome in human infants. The medical term for blue-baby syndrome, methemoglobinemia can be

caused if excessive nitrate levels are present in the stream. The EPA has set a limit of 10 mg/L as NO_3-N or 45 mg/L as NO_3. Stream analysis was performed to assess the impact of nitrate-nitrogen in the system. Since the highest nitrate-N concentrations ever recorded were in MW1, the background well, it is safe to assume that the lagoon system is anaerobically converting nitrate into nitrogen gas. The highest nitrate-N concentrations, due to the lagoon, were only once above the EPA maximum contaminant level of 10 mg/L, which occurred in MW3. This event occurred almost four years ago with current levels below 1.0 mg/L. However, if one assumes a worst case scenario where 10 mg/L of nitrate is put into the aquifer by the lagoons for one month continuously, there is no corresponding impact on the stream. Although this result is based on assuming specific aquifer biological degradation rates for nitrate under anaerobic conditions (not a perfect assumption for non-aquifer conditions), persons located one mile downstream from the lagoon site will experience no additional nitrate in their surface water. The lagoons will pose no additional hazard to the stream water quality. Nitrate-nitrogen poses a larger hazard if subsurface flow is intercepted by tile-line drainage.

Although actual drain tile design records were not consulted, this subsurface drain probably intercepts the Kirkwood lagoon's groundwater flow pattern based on the local flow direction of northeast (54.8°) and the discharge angle of the tile line outlet to the creek. Therefore, concentrations seen in the farthest MW2 are assumed to reach the aquifer, due to subsurface tile-line "short-circuiting." Short-circuiting will increase nitrate-nitrogen and other contaminants' transport rates to the creek. Therefore, for contaminant transport calculations, this report will assume concentrations in MW2 through MW4 are representative of in situ stream concentrations. This scenario and assumption is a worst case scenario, since in reality, biodegradation will occur between MW2 and the creek, and not all contaminants will enter the drain tile.

Several other stream characteristics are important to the overall quality of this water body. The stream's dissolved oxygen concentration, temperature, and saturation level of nutrients capable of causing eutrophication, are all serious water quality issues.

Dissolved oxygen levels are important for a balanced ecosystem. Aquatic life forms require oxygen to survive. Microorganisms use dissolved oxygen to degrade organic material discharged to the stream. Algae and other aquatic plants also require oxygen to survive. Thus, "DO is a surrogate variable for the general health of the aquatic ecosystem. The impact of low DO concentrations or of anaerobic conditions is reflected in an unbalanced ecosystem, fish mortality, odors, and other aesthetic nuisances" (Thomann and Mueller 1987). The USEPA recommends DO levels near 5.0 mg/L to protect aquatic life. Dissolved oxygen analysis will not be conducted during this study since no dissolved oxygen levels were ever recorded at the Kirkwood site.

Temperature also affects water quality. "Excess heat may alter an aquatic ecosystem in several ways including: 1) direct lethal effect on sensitive plants or animals, 2) indirect long-term effects on the aquatic ecosystem through effects on growth and/or reproduction, 3) indirect effects through changes in the species distribution of the system" (Thomann and Mueller 1987). Although important to water quality analysis, this parameter was also not analyzed by the Iowa Department of Natural Resources.

Eutrophication is the excessive growth of aquatic plants, both attached and freely moving, to levels that are considered to be an interference with desirable water uses. This is caused by an excessive amount of nutrients, such as nitrogen and phosphorus, in the water body. Eutrophication causes large diurnal variations in DO levels, potentially harming local fish species by reducing oxygen levels below those needed to survive. Although the Kirkwood lagoons contribute nitrogen to this stream, agricultural practices such as fertilizers and surface runoff are primarily responsible for eutrophication in streams. According to Tchobanoglous and Burton, "a simple criterion is that algal blooms will tend to occur if the concentration of inorganic nitrogen and phosphorus exceed respective values of 0.3 mg/L and 0.01 mg/L (1991). Total nitrogen is composed of organic nitrogen, ammonia nitrogen, and nitrite and nitrate nitrogen. Of these forms, only ammonia-N, nitrite-N, and nitrate-N are available for phytoplankton growth. The Kirkwood stream has measured ammonia-N levels at or below the laboratory's detection limits of 0.5 mg/L. No information is available for phosphorus levels in the stream. However, if one assumes 1-D transport, the stream would

be considered eutrophic based on nitrogen levels alone. Thus, whether or not the lagoons contribute to the stream's water quality is unclear. The key observation, however, is that the stream is potentially unsafe for aquatic life since increased nutrient levels could ultimately deteriorate DO levels below life-sustaining levels.

Contaminant Transport/Groundwater Quality

The most important data for contaminant transport analysis is the concentration profiles, listed in Appendix B. Notice how the graphs of concentrations versus time vary inversely with distance from the lagoons. Monitoring well #1 has concentrations that are considered "background" concentrations and gradually decrease over time. Monitoring wells #2 through #4 are considered representative of the groundwater aquifer characteristics since their axis of symmetry is parallel with the groundwater flow direction. One key thing that needs to be studied at this site is the velocity distributions of chloride anions between these three monitoring wells.

A rough estimate of hydraulic conductivities was calculated based on chloride transport rates between wells #2 through #4 (See Appendix H). The time for a measured increase in chloride concentrations above background in the aquifer between MW4 and MW3 was 306 days. This produces a velocity of the chloride anion of 7.3×10^{-5} cm/sec. The actual hydraulic conductivity in this region based on this tracer test is 1.2×10^{-4} cm/sec. This is almost identical to the slug test results for MW3. The chloride anion transport time was 91 days from MW3 to MW2. The chloride velocity is 2.58×10^{-4} cm/sec in this aquifer region. The hydraulic conductivity in this region is approximately 4.3×10^{-4} cm/sec. This result is approximately the same value for MW3's hydraulic conductivity. However, in comparison with MW4, this value is greater than the slug test results. This difference can be attributed to the sand pockets immediately between the MW4 and MW2. However, below this region, the hydraulic conductivity decreases to values on the order of 10^{-5} cm/sec. Based on this last aquifer region's travel time for chloride, the groundwater flow takes approximately 2.5 years to reach the stream from the lagoon. If short circuiting occurs through subsurface tile-lines or high conductivity soil (sand/gravel), contaminant travel times could be faster than 2.5 years.

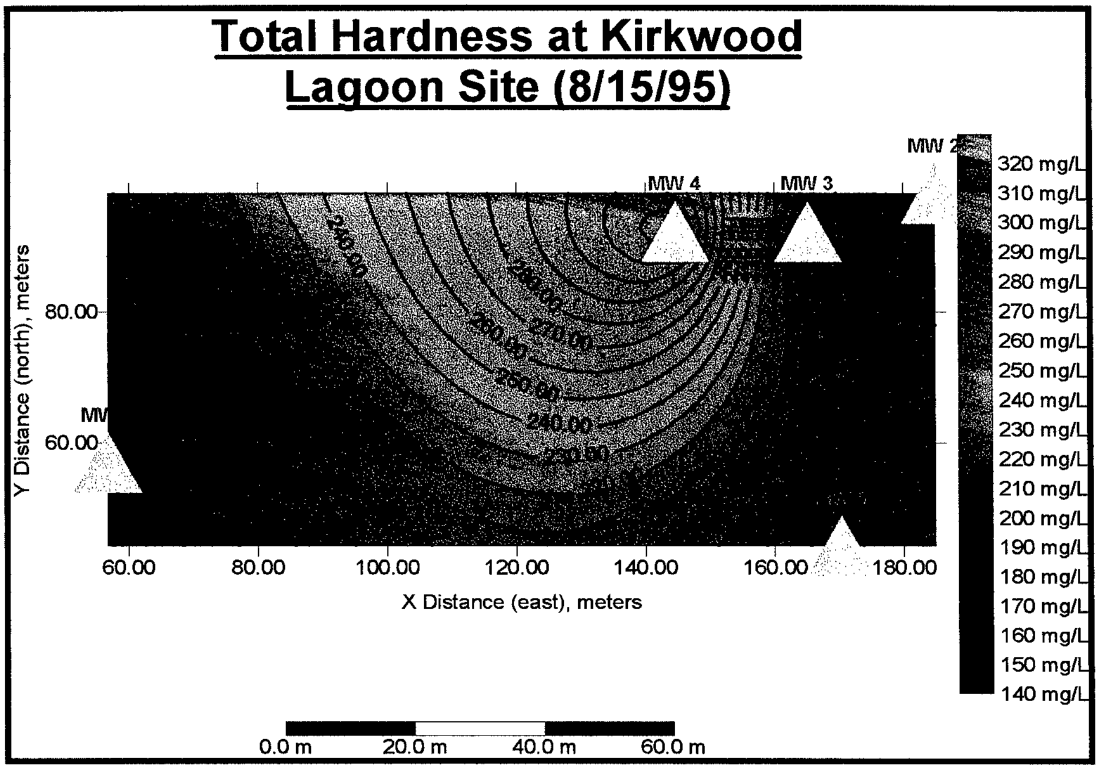


Figure 32. Total hardness (Ca^{2+} & Mg^{2+}) at Kirkwood lagoons.

Other inorganic ions such as hardness, sodium, and potassium will also travel in the aquifer. Total hardness is made up of the divalent cations calcium and magnesium. See Figure 32 for a concentration plot of these two cations. These two ions appear to have a relatively high background level at the site. This could be due to the natural limestone and shale deposits underlying the site. Another reason for the high calcium and magnesium levels in the lagoon is due to the actual animal waste products. The inorganic substances are added to swine feed as nutrients. Therefore, it is not unlikely to see high levels of these ions in the waste products. The impact of hardness on water quality near the Kirkwood lagoons is minor. Hardness can contribute to scaling of pipes and bathroom facilities, however, water softening will correct this problem easily.

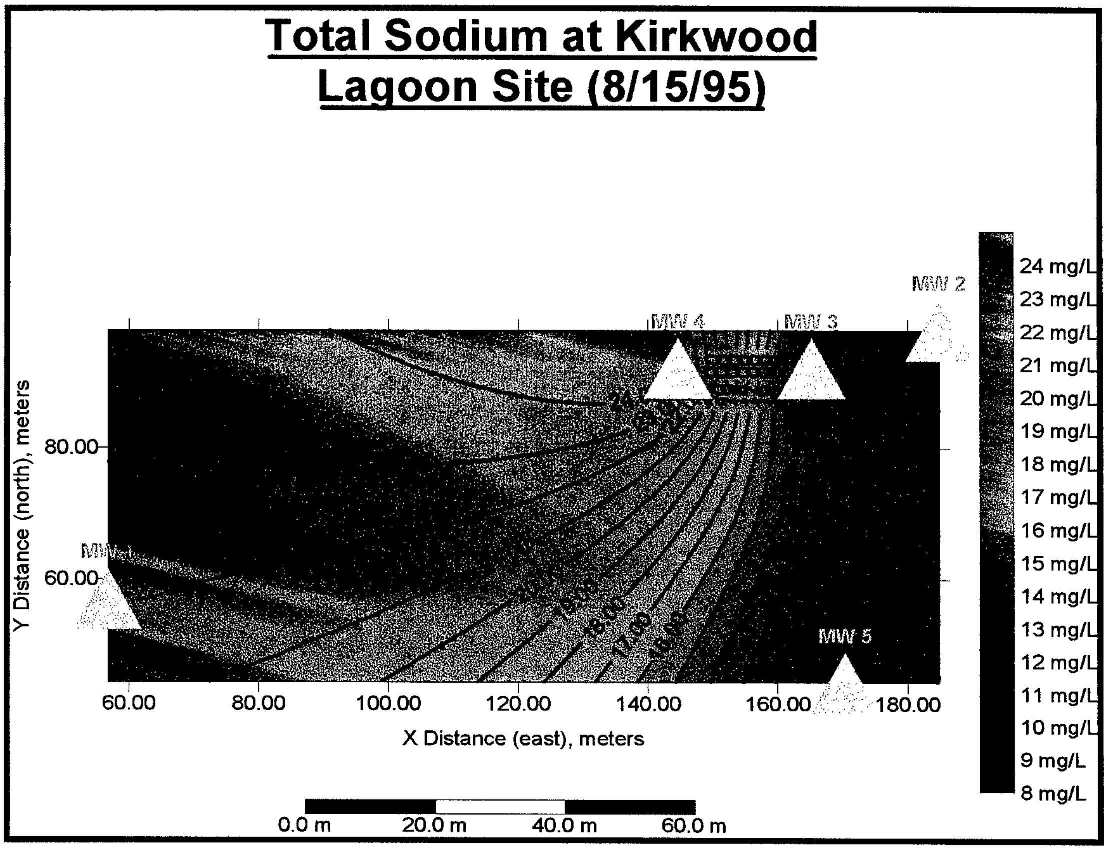


Figure 33. Total sodium (Na^+) at Kirkwood site.

Sodium levels in the lagoon are also attributed to nutrients added to the swine feeding material. See Figure 33 for sodium levels in all five monitoring wells. Sodium levels are actually higher in MW 1 (background) than in wells below the lagoons and in the direction of groundwater flow. An explanation of this is that sodium might be ion-exchanged with the clay liners of the lagoons or used up as a nutrient for growth by the aquifer's microbial community. Impacts of sodium on groundwater quality will also be minor. Those people experiencing high-blood pressure will not want to drink this source since it could be a potential source for increased blood pressures. In general, most water supply users may only notice a slightly salty taste of the water supply as this ion combines with chloride to form table salt.

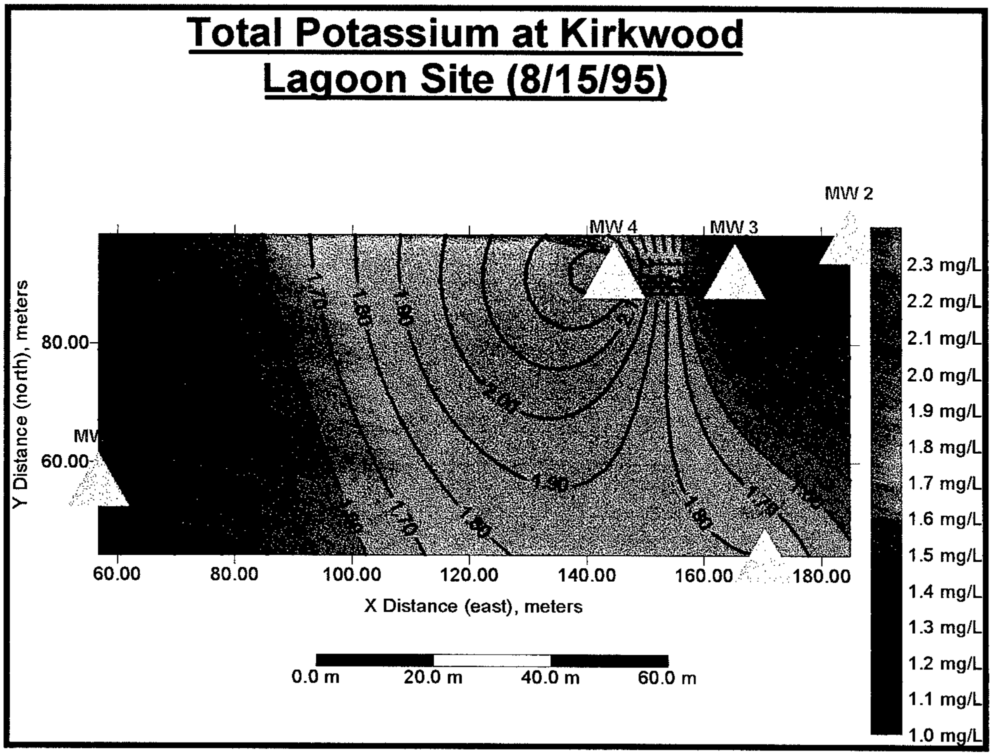


Figure 34. Total potassium (K^+) at Kirkwood site.

Potassium is also not a major health hazard in drinking water supplies. See Figure 34 for a concentration contour map of potassium at the Kirkwood site. The source of potassium in this aquifer is primarily due to feed additives. This nutrient is also metabolized during anabolic respiration by microorganisms as a much needed nutrient for microbial growth. The total impact of potassium on human health will be small.

The sodium absorption ratio for this soil is calculated using:

$$\boxed{SAR = \frac{\left[Na^+\right]}{\left[\frac{(Ca^{2+} + Mg^{2+})}{2}\right]^{0.5}}}$$

Equation 18. Sodium absorption ratio (Tchobanoglous and Burton 1991).

where SAR = sodium absorption ratio and the cations are expressed as meq/L. The soil at the Kirkwood site has an average SAR of 0.27 $mmol^{1/2}$, a slightly saline soil which is well below toxicity levels for irrigation water for crops (See Appendix H for calculations) (Cuenca

1989). Thus, total cation levels in lagoon water will pose no environmental hazard to crops when used for irrigation purposes.

Colloidal Transport

Colloids are basically any fine grained material that can be suspended. Several materials can act as colloids including clays, fulvic and humic acids, organic ligands, minerals, and microorganisms like viruses. Colloids are particles with diameters less than 1 to 10 μm. These particles can be the result of chemical precipitation, biological activity, disaggregation, or organic macromolecules like humus. Colloidal transport is important when dissolved organic carbon levels are high, fractured or porous aquifers with relatively high flow rates are encountered, or some type of alteration is done on the aquifer to produce colloids. Such alterations could be due to sparging a well for chemical analysis samples, air drilling in or around previously installed monitoring wells, or through the use of drilling mud during new well installation.

The reason colloidal transport is important to contaminant transport is because colloids greatly enhance the transport of dissolved solutes in an aquifer. Solutes can partition on to the mobile colloid particle and actually move faster than the corresponding groundwater flow. This is due to the size exclusion effect of smaller pore spaces. The size exclusion effect is basically the "bully" syndrome in action. For example, if a bully is in a classroom of other young school children, when the recess bell rings, the bully is the first one through the door to the outside. The bully can get away with this since he/she is the biggest and toughest person in the class. Everyone else lets them go through the class door first since they are bigger. Colloids act in the same way as the bully. Colloids can go through soil pore spaces faster because they are bigger and are limited to transport through bigger pores. Bigger pores means faster pore water velocities. Increased velocities contributes to faster transport times. Thus, colloids play an important role in contaminant transport and should be analyzed when doing a site investigation. Although the Kirkwood site doesn't have any recorded data on dissolved organic carbon levels, the total organic carbon levels appear to be increasing which could indicate colloidal transport.

Biodegradation

Biodegradation is important at the Kirkwood site since nitrification and denitrification convert ammonia and nitrate from the lagoons into either more nitrate-nitrogen or nitrogen gas. This process is based on the nitrogen cycle using the organic animal waste material as a carbon source.

There are two types of microbial metabolism. Anabolism is the synthesis of cell parts including protein, RNA, and DNA from a carbon source. This type of process requires energy to convert the carbon source ("food") into cell parts. The products formed under this type of reaction are more reduced than the carbon substrate. Several major nutrients are needed for growth including: carbon, hydrogen, oxygen, nitrogen, potassium, sulfur, phosphorus, magnesium, calcium, sodium, and iron.

Catabolism is the second major type of microbial metabolism. This is the process of breaking down chemicals to be used as food and energy for cell growth. The products in this type of process are more oxidized than the carbon substrate. Catabolism works through redox reactions involving an electron donor and electron acceptor. Typical electron donors are glucose, methanol, acetate, and nitrite. Electron acceptors include: oxygen, nitrate, sulfate, and carbon dioxide.

Several types of microbial redox reactions occur. Fermentation, aerobic respiration, and anaerobic respiration are common examples. Fermentation is the anaerobic metabolism of carbohydrates. This is a low energy yielding process that produces final products which are not completely oxidized. Fermentation products can be used by other microorganisms as food sources, or substrates. An example of this process is the production of beer.

Aerobic respiration uses catabolic reactions to produce energy using organic and inorganic compounds as the electron donors; and oxygen as the electron acceptor. This is a very high energy yielding process. An example of this type of process is the production of nitrate from ammonia-nitrogen.

Anaerobic respiration also uses catabolic reactions to produce energy using organic compounds as electron donors; and nitrate, iron III, sulfate, or carbon dioxide as electron

acceptors. This process yields less energy for microorganisms than aerobic respiration, but higher energy yields than fermentation. Denitrification is an example of this type of process.

Bioremediation at the Kirkwood site is very pronounced. Evidence of microbial degradation is ultimately observed in the odors of the lagoon. Anaerobic respiration produces hydrogen sulfide (rotten egg smell), which could easily be smelled from the banks of the lagoon. Denitrification is also occurring at the lagoon. This is clearly evident in the reduction of NO_3^-/Cl^- ratio (See Appendix B), as discussed earlier. Ultimately, biological degradation appears to be reducing monitored chemical constituents to below hazardous levels, as set by the EPA.

ENVIRONMENTAL EFFECTS OF LAGOONS ON WATER QUALITY

Time-line for Contamination

Transport velocities will not move contaminants to the stream in less than 300 days, based on contaminant transport calculations. However, a more realistic transport estimate predicts contaminants reaching the stream in approximately 2.5 years. This data is supported by actual transport velocities of chloride between monitoring wells 2-4. Additionally, seepage from the both lagoons is minor—the combined total is less than 1 gallon of liquid per day.

Biological degradation rates were also calculated for the Kirkwood lagoons. The results show that nitrate-N levels will not pose health hazards to water users of the stream or the underlying aquifer since concentrations are below the EPA maximum contaminant level (10 mg/L). However, the stream will be impacted by the nutrient levels in the water (either from the lagoons or surrounding agricultural practices) causing eutrophication and ultimately the depletion of dissolved oxygen levels downstream from the Kirkwood lagoons.

Intensity of Impact

The impact of this lagoon system is minimal on the surrounding community. Although Linn county is in one of the highest population density regions for Iowa (18 total

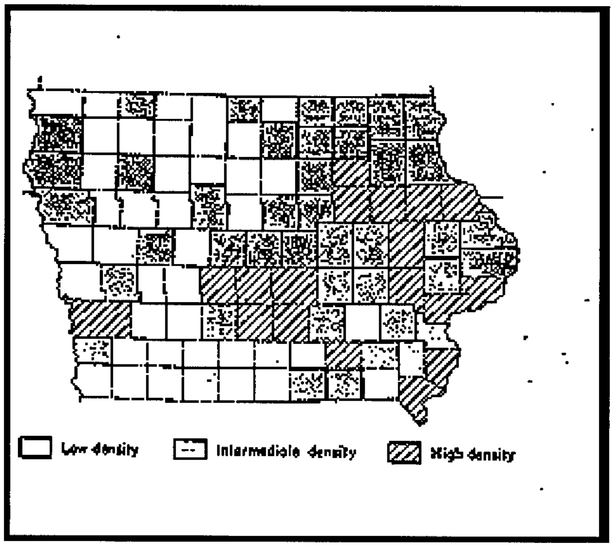


Figure 35. Iowa population densities (Wilson 1990).

Iowan counties comprising almost 33% of the states population) (Wilson 1990), the total effect of the lagoon will not be felt by the surrounding community due to low seepage rates and chemical concentrations, biodegradation, and other factors, already discussed. See Figure 35 for a map of the Iowa population density. Potentially, the lagoons' impact on the environment might become more severe in the future as the soil cation exchange capacity reaches saturation and more ammonia-N leaches into the groundwater. Increasing stream ammonia concentrations could be seen within a year of this study, based on measured monitoring well and stream water quality samples.

Human Health Effects

Currently, the effect of these lagoons on human health is small. If one assumes a water user locates a pumping well on the bank of the north lagoon (MW4) and begins withdrawing water from this well to supply a family of four with drinking water, health effects will be minimal, and well below the EPA's hazard index. See Table 6 for chemicals and reference doses (in either mg/L or mg/kg*day) used for health hazard calculations.

Chemical Name	Oral Reference Doses mg/kg*day	Date	Inhalation Reference Doses mg/kg*day	Date	EPA Standards MCL or SMCL
Ammonia	N/A		2.86×10^{-2}	5-1-91	-
Nitrate	1.6×10^{0}	5-1-91	N/A		10.0
Nitrite	1.0×10^{-1}	8-1-91	N/A		1.0
Fluoride	6.0×10^{-2}	6-1-89	N/A		4
Chloride	N/A		N/A		250
Sodium	N/A		N/A		20
Sulfate	N/A		N/A		400/500

Table 6. Chemical contaminants and accompanying human health effects (LaGrega et al. 1994).

The health hazard determination for this drinking water source is only as good as the data that helps develop it. Thus, to ensure protection, sampling should also be performed on each MW to determine other chemicals present, including organic chemicals, pesticides, and other synthetic compounds. However, those materials were not sampled or studied in this report.

Based on the chemicals listed above and EPA hazard calculations presented in Appendix J, only recent chloride levels would adversely impact human health by drinking water pumped directly from monitoring well 4. Ultimately, even this impact is minor, since chloride only imparts a salty taste to water. However, if the water user was under treatment for heart problems, consideration should be made to treat this water for excessive chloride levels before consumption.

CONCLUSIONS

Summary of Results

Chloride was the only monitored constituent that would adversely effect human health and public safety due to the lagoons. Nitrate levels in both groundwater and surface water resources are below EPA standards, and ultimately, below most analyzers detection limits. Most of this decrease in concentration is due to active microbial degradation in the aquifer. Ammonia-N levels appear to be increasing, apparently due to exceeding the soil's cation exchange capabilities and consequently leaching it into the aquifer. Sulfate levels will not impact human health conditions, but may affect public support for the lagoons due to the production of hydrogen sulfide and odor. The swine waste lagoons at the Kirkwood Community College do not pose a major environmental, human health, or public safety problem to the surrounding community, based on monitored chemical constituents.

Summary of Results—At a Glance:

Advantages of Kirkwood Lagoons:

- Lagoons are operated well below maximum design capacity.
- Low (< 4 liters) seepage rates from lagoons.
- Low chemical concentrations of ammonia-N and nitrate-N in monitoring wells.
- Lagoon is biologically sealing.

Disadvantages of Kirkwood Lagoons:

- Anaerobic lagoon is under-diluted, causing operational inefficiencies and odor.
- Sand pockets are clearly evident near the Kirkwood lagoons, potentially increasing contaminant transport speeds towards the stream.
- Nitrogen levels above (0.3 mg/L) could potentially cause eutrophication in stream.
- Chloride levels are a potential health hazard for heart-care patients using the water.
- Odor levels from hydrogen sulfide are high, due to incomplete microbial degradation.
- Long aquifer travel times, so more research is needed at this site.

APPENDIX A: Lagoon Design

Table 7-1. Single stage swine lagoon volumes.
Also use for first stage of two-stage lagoons. Always provide 1'-2' of freeboard.

7-1a. Individual animals.

Animal	Weight, lb	Climatic zone, Fig 7-1						
		1	2	3	4	5	6	7
		ft³/hd						
Sow and litter	400	585	500	440	390	350	320	295
Prenursery pig	20	60	50	45	40	35	35	30
Nursery pig	55	160	135	120	105	95	90	80
Growing pig	115	330	280	245	220	200	180	165
Finishing pig	190	540	465	405	360	325	295	270
Gestating pig	325	260	225	195	175	160	145	130
Boar	400	320	275	240	215	195	175	160

7-1b. Swine operations.
Based on 16 pigs sold per productive sow-yr. Lagoon volume per productive sow accounts for all animals in the operation such as pigs in nursery, growing, etc. and boars.

Operation	Climatic zone, Fig 7-1						
	1	2	3	4	5	6	7
Feeder pigs produced sold at 50 lb (ft³/productive sow)	740	630	560	490	450	410	370
Pigs fed 50-220 lb (ft³/pig sold-yr)	190	160	140	120	110	100	90
Farrow to finish (ft³/productive sow)	6,660	5,720	5,010	4,480	4,070	3,710	3,400
(ft³/pig sold-yr)	420	360	310	280	250	230	210

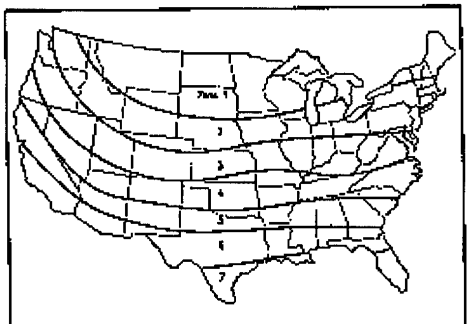


Fig 7-1. Climatic zones for anaerobic lagoons.
Based on volatile solids loading rates recommended by the American Society of Agricultural Engineers (ASAE).

Lagoon Construction

Location

Locate a lagoon as far from the farm home as practical, and where the prevailing winds will carry odors away from houses. Court action can force you to revise your waste management system to stop the production of objectionable odors. To some people, lagoon odors are objectionable at distances of ½ mile and detectable at distances of a mile or more.

Locate the lagoon near the waste source. If the lagoon is downhill from the source, gravity can transport the waste. A sump and submersible sewage lift pump can elevate wastes into a lagoon if necessary.

Locate the lagoon over impervious soil, where bottom and sidewalls can be impervious. Soil Conservation Service and Agricultural Extension Service personnel can evaluate your soil. Avoid a site where the bottom of the lagoon would be less than about 20' above limestone, depending on soil type. Remove any field tile in the area.

Lagoons on some soils require sealing with liners, clay, or soil cement. Sealing may be accomplished biologically—animal waste solids are a good sealant in many soils, but this process takes time. Clay or soil cement delays leaking while biological sealing develops. Membrane sealing (plastic, vinyl, rubber, etc.) is positive and effective, but is expensive and difficult to install.

Consult your Agricultural Extension Service or state health or pollution control authorities for regulations governing the location of lagoons relative to wells. If the lagoon must be built near a locally recharged shallow well, the bottom of the well must be higher than the top of the lagoon.

Table 7-2. Volumes for the second stage of two-stage lagoons.
Use Table 7-1 to size the first stage of a two-stage lagoon. Second stage lagoons are not as dependent on climate as first stage lagoons. This table is for typical Midwest climate where evaporation is about equal to rainfall. Provide an extra 1'-2' of depth if rainfall greatly exceeds evaporation in your area. Always provide 1'-2' of freeboard.

7-2a. Individual animals.

Animal	Weight, lb	ft³/hd
Sow and litter	400	345
Prenursery pig	20	16
Nursery pig	55	36
Growing pig	115	75
Finishing pig	190	125
Gestating sow	325	105
Boar	400	130

7-2b. Swine operations.
Based on 16 pigs sold per productive sow-yr. Lagoon volume per productive sow accounts for all animals in the operation such as pigs in nursery, growing, etc. and boars.

Operation	ft³/pig sold-yr	ft³/productive sow
Feeder pigs produced, sold at 50 lb	—	300
Pigs fed, 50-220 lb	40	—
Farrow to finish	50	750

Inlets and outlets

Extend lagoon inlets beyond the cut slope of the embankment to reduce erosion and to uniformly distribute the waste load. A lagoon freezes over in very cold weather. If this is likely, either avoid direct loading, or allow enough storage capacity above ice level. With an exposed inlet, increase inlet height to leave room above the ice for winter manure. Or, provide separate manure storage until the lagoon thaws. See Fig 4-9 for inlets. When planning diversions for surface water, consider that some surface water may be needed for dilution. Locate pumping outlets for irrigation away from inlets to reduce transfer of unliquefied solids.

2.1

2. ANIMAL WASTE CHARACTERISTICS

The quantity and composition of wastes produced influence livestock waste facility design. The properties of manure depend on several factors: animal species; ration digestibility, protein, and fiber content; and animal age, environment, and productivity. The waste system also handles added bedding, soil, water, hair, etc.

Waste with 20%-25% solids content (75%-80% moisture content) can usually be handled as a solid, i.e. it can be stacked and can be picked up with a fork loader. Liquids need to be drained and the waste dried or bedding added to get solid waste. In the 10%-20% solids content range, handling characteristics vary depending on the type of solids present. In this range, the percent solids content does not necessarily define handling characteristics.

Waste with 4%-10% solids content can usually be handled as a liquid, but may need special pumps. Waste with 0%-4% solids content is handled as a liquid with irrigation or flushing consistency. Liquids which have had the larger solids settled or filtered out or wastes with dilution water added may have 4% or less solids.

Manure

Table 2-1 lists manure properties. Because of the variations in animal manure properties, the values

Table 2-1. Manure production and characteristics as produced.
Values are approximate. The actual characteristics of a manure can easily have values 30% or more above or below the table values. The volumes of waste that a waste handling system has to handle can be much larger than the table values due to the addition of water, bedding, etc. For example, liquid waste systems for swine farrowing and gestation units may have to handle twice as much waste volume as indicated; swine nurseries 3-4 times as much, because of large amounts of wash and wasted water.

Animal	Size, lb	Total manure production lb/day	ft³/day	gal/day	Water, %	Density lb/ft³	TS lb/day	VS lb/day	BOD_5 lb/day	Nutrient content, lb/day N	P_2O_5	K_2O
Dairy cattle	150	13	0.21	1.6	87.3	62	1.8	1.5	0.24	0.064	0.03	0.05
	250	22	0.35	2.6	87.3	62	3.0	2.5	0.40	0.106	0.04	0.09
	500	43	0.69	5.2	87.3	62	6.0	5.0	0.80	0.213	0.09	0.17
	1,000	86	1.39	10.4	87.3	62	12.0	10.0	1.60	0.425	0.17	0.34
	1,400	120	1.94	14.5	87.3	62	16.8	14.0	2.24	0.595	0.24	0.48
Beef cattle	500	30	0.48	3.6	88.4	63	4.8	3.4	0.6	0.17	0.18	0.15
	750	45	0.71	5.3	88.4	63	6.4	5.4	1.2	0.26	0.19	0.22
	1,000	60	0.95	7.1	88.4	63	8.5	7.2	1.6	0.34	0.25	0.30
	1,250	75	1.19	8.9	88.4	63	10.6	9.0	2.0	0.43	0.31	0.38
Cow[a]		63	1.00	7.5	88.4	63	7.3	6.2	1.7	0.36	0.273	0.313
Swine												
Nursery pig	35	2.3	0.04	0.3	90.8	62	0.39	0.30	0.11	0.02	0.012	0.012
Growing pig	65	4.2	0.07	0.5	90.8	62	0.72	0.55	0.20	0.03	0.022	0.023
Finishing pig	150	9.8	0.16	1.2	90.8	62	1.65	1.28	0.47	0.07	0.050	0.054
	200	13.1	0.21	1.6	90.8	62	2.20	1.71	0.63	0.09	0.067	0.072
Gestating sow	275	9.0	0.15	1.1	90.8	62	0.82	0.66	0.27	0.07	0.050	0.050
Sow and litter	375	22.5	0.36	2.7	90.8	62	2.05	1.64	0.68	0.10	0.055	0.055
Boar	350	11.5	0.19	1.4	90.8	62	1.04	0.84	0.34	0.09	0.064	0.064
Sheep	100	4	0.06	0.4	75.0	64	1.10	0.92	0.12	0.042	0.020	0.039
Poultry												
Layers	4	0.21	0.0035	0.026	74.8	60	0.054	0.040	0.013	0.0029	0.0025	0.0014
Broilers	2	0.14	0.0022	0.016	74.8	63	0.044	0.034	0.0024	0.0017	0.0009	—
Horse	1,000	51	0.81	6.06	79.5	63	15	10	1.7	0.30	0.161	0.301

Source: American Society of Agricultural Engineers, data adapted from 1992 ASAE standard D384.1
Swine data based on Purdue University findings
[a]Not ASAE data

TS = Total solids (taken from 1992 ASAE data)
VS = Volatile solids (taken from 1992 ASAE data)
BOD_5 = The oxygen used in the biochemical oxidation of organic matter in 5 days at 68 F. A standard test to assess wastewater strength.(taken from 1992 ASAE data)
N = Total nitrogen
Elemental P (Phosphorus) = 0.44 x P_2O_5
Elemental K (potassium) = 0.83 x K_2O
Densities are from 1992 ASAE Standards
Nutrient contents taken from Purdue University data
Cow = 1.05 ft³/day

usually double those for water flushing for design

estimates

$\frac{BOD}{\text{total solids}}$ ratio ↑

low = most of total solids are not digestable for bacteria (can't be used by bacteria) (non biodegradable)

Design Calculations

Appendix

Manure Content

130 sow farrowing operation: ~ 375 lb

worst case!!

$$\frac{130\ \text{hd}}{} \Big| \frac{0.36\ \text{ft}^3}{1\ \text{hd}\cdot\text{day}} \Big| \frac{365\text{d}}{1\ \text{yr}} = 17{,}082\ \text{ft}^3/\text{yr}$$

or 127,782 gal/yr

680 - hog finishing operation:

Assume 200 lb/hd (worst case)

$$\frac{680\ \text{hd}}{} \Big| \frac{0.21\ \text{ft}^3}{\text{hd}\cdot\text{day}} \Big| \frac{365\text{d}}{\text{yr}} = 52{,}122\ \text{ft}^3/\text{yr}$$

or

389,899.64 gal/yr

* Flushing factor = 2

Total manure production: = (389,900 gal/yr + 127,782 gal/yr)2

= 1,035,364 gal/yr w/dilution flushing

Zone 2:

Table 7.1a (1st Stage)

Sow's area = $500 \text{ ft}^3/\text{hd} \times 130 = 65{,}000 \text{ ft}^3$

Finishing area = $465 \text{ ft}^3/\text{hd} \times 680 = 316{,}200 \text{ ft}^3$

Table 7.2 (2nd Stage)

Sow = $345 \text{ ft}^3/\text{hd} \times 130 = 44{,}850 \text{ ft}^3$

finishing = $125 \text{ ft}^3/\text{hd} \times 680 = 85{,}000 \text{ ft}^3$

Needed:

1st Stage Volume = $381{,}200 \text{ ft}^3$

2nd Stage Volume = $129{,}850 \text{ ft}^3$

Bank slope = $\frac{1'}{1.5'}$ (6.5' freeboard)

North Lagoon Sizes = $140' \times 160'$

South Lagoon Sizes = $150' \times 100'$

* Assuming Lagoons pumped 1 time/yr

Depth estimate (Box)

1st Stage = $\frac{381{,}200 \text{ ft}^3}{140' \times 160'}$ = depth = 17' (must be deeper since a trapezoid)

2nd stage = $\frac{129850}{150 \times 100}$ = 8.7'

* Both Lagoons are submerged

Given:

680 finishing pigs

130 sow + litter

680 × 0.16 ft³/day manure = 108.8 ft³ manure/day

680 × 1.65 lb/d = 1122 lb/d total solids

680 × 1.28 lb/d = 870 lb/d Volatile solids

130 × 0.36 ft³/d = 46.8 ft³/d

130 × 2.05 lb/d = 266.5 lb/d total solids

130 × 1.64 lb/d = 213 lb/d Volatile solids

Total Volatile solids production = 1083 lb/d < 6000 lb/d VS

Table 1 → Loading Rate = 5.0 lb VS/day / 1000 ft³

Table 3-1

Finishing Pig = 680 x 150 lb = 102,000 lb pigs

1st Stage = 102,000 lb x 2.11 = 215,220 ft³

2nd Stage = 102,000 lb x 1.24 = 126,480 ft³

Sow + litter = 130 x 375 lb = 48750 lb

1st Stage = 48750 lb x 1.07 = 52163 ft³

2nd Stage = 48750 lb x 0.79 = 38513 ft³

1st - Total Size = 215,000 ft³ + 52163 ft³ = 267,163 ft³ → 7565 m³

2nd Total Size = 38513 ft³ + 126480 ft³ = 165,000 ft³ → 4672 m³

Lagoon Minimum depth

Volume should not be below minimum design volume

1st Stage

Finishing pigs = 102,000 lbs × 1.71 = 174420

Sow + litter = 48750 lbs × 0.87 = $\underline{42413}$

216833 ft^3 needed

= $\underline{\underline{6140\ m^3}}$ minimum volume

2nd Stage

Finishing pigs = 102,000 lbs × 0.39 = 39780 ft^3

Sow + litter = 48750 lbs × 0.35 = $\underline{17063\ ft^3}$

= 56843 ft^3

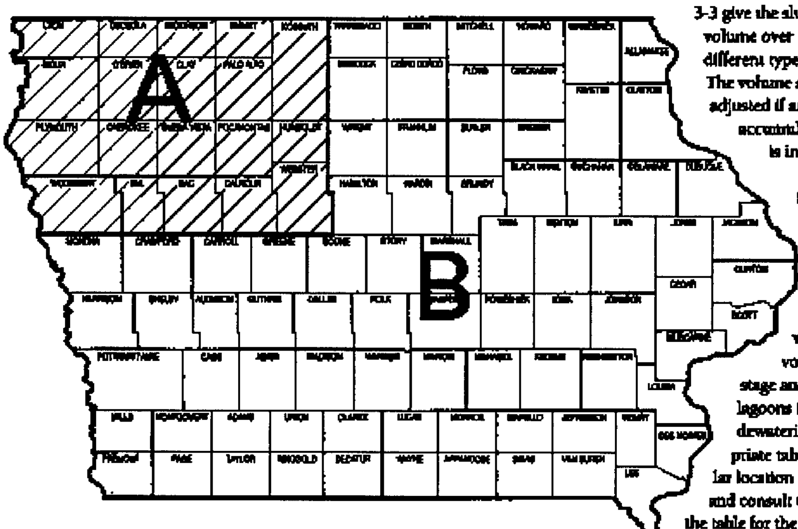
= $\underline{\underline{1609.6\ m^3}}$ manure storage

Lagoon Design Parameters

Table 1. Maximum loading rate of volatile solids for anaerobic lagoons in Iowa

Animal Type	Volatile Solids Production Rate (lb/day)	Location (see map)	Loading Rate (lbvs/day/1000 ft³)
Beef	All	A,B	10.0
Others Swine Dairy Poultry	> 6,000	A,B	4.0
	< 6,000	A*	4.5
		B	5.0

*Lagoons in area A use 5.0 as maximum loading rate if sulfate concentration in water supply is below 500 ppm.



partially removed from the liquid manure before entering the lagoon, the total lagoon design volume can be reduced by up to 25 percent. Solids can be removed from the manure by using a settling tank or a mechanical separator. Solids can be land applied or perhaps composted before land application.

3. Dilution volume
Iowa Code requires that the dilution volume for animal manure lagoons should not be less than 50 percent of the minimum design volume. Tables 3-1, 3-2, and 3-3 use 50 percent of minimum design volume as the dilution volume for lagoon designs. Dilution water includes all extra water such as building wash water, spillage from animal watering devices, feedlot runoff, direct precipitation, and fresh water pumped from a well or a stream.

4. Sludge accumulation volume
Sludge accumulation volume accounts for those manure solids that can not be liquefied by bacteria and that gradually accumulate at the bottom of the lagoon as sludge. Fractions of total solids that are assumed to stay as sludge are 50 percent volatile solids plus all the fixed solids. To maintain the minimum design volume for manure treatment, the volume of sludge accumulation over the time between sludge removal must be considered. Tables 3-1, 3-2, and 3-3 give the sludge accumulation volume over 10 years for different types of animals. The volume should be adjusted if another sludge accumulation period is intended.

Determining recommended volume
Tables 3-1, 3-2, and 3-3 recommend component volumes and total volume for single-stage and two-stage lagoons for once-a-year dewatering. Use the appropriate table for your particular location and operation size, and consult the left column of the table for the type of animals raised. Across from this column, find the minimum design volume and total volume values for single-stage or two-stage lagoons that are dewatered once a year. Adjust the manure storage volume and total volume accordingly if another dewatering practice is planned. For example, if the lagoon is dewatered twice a year, the manure storage volume shall be half the number in the table, and the total volume shall be reduced accordingly. **But the minimum design volume does not change.**

Table 2. Manure and solids production by different types of animals

Animal Type	Average Weight (lb.)	Total Manure Production (cu. ft./day)	Total Solids Production (lb./day)	Volatile Solids Production (lb./day)
Swine				
Nursery pig	35	0.04	0.39	0.30
Growing pig	65	0.07	0.72	0.55
Finishing pig	150	0.16	1.65	1.28
Gestation sow	275	0.15	0.82	0.66
Sow and litter	375	0.36	2.05	1.64
Boar	350	0.19	1.04	0.84
Cattle				
Dairy	1,000	1.39	12.00	10.00
Beef	1,000	0.96	8.50	7.20
Poultry				
Layers	4	0.0035	0.064	0.048
Broilers	2	0.0022	0.044	0.034

Data Source: *ASAE Standards* D384.1, 1993

The numbers in tables 3-1, 3-2, and 3-3 represent the volume of the lagoon in cubic feet per pound of body weight of the animals. Multiply the number by the total body weight of all the animals producing manure for the lagoon to obtain the grand volume of the lagoon. The total body weight of animals is the product of the number of animals and the average weight of the animals. For different animals and different weights, all the volumes must be determined and added together to give the total volume. The total volume does not include the safety volume. Two-foot freeboard must be provided as a safety factor. The freeboard is the section of the dam built above the highest liquid level in the lagoon.

The liquid depth in the lagoon should be made as deep as possible if soil and other site conditions allow. The minimum depth for a lagoon in Iowa is 8 feet.

Working Example:

A swine producer has 550 growing pigs and 550 finishing hogs near Ames. The producer wishes to construct a two-stage anaerobic lagoon that has one-year manure storage capacity.

Determine lagoon volume:

Total body weight of 550 growing pigs and 550 finishing pigs:

From Table 2, find the average body weight: 65 lb. for a growing pig and 150 lb. for a finishing hog.

Total body weight of 550 growing pigs = 550 pigs × 65 lb./pig = 35,750 lb.

Total body weight of 550 finishing pigs = 550 pigs × 150 lb./pig = 82,500 lb.

Total volume of a two-stage lagoon is shown in the worksheet table on page 5. The information in the worksheet table is taken from Table 3-1.

Total volume of the first-stage lagoon for treating manure produced from 550 growing pigs and 550 finishing hogs will be 249,792 cu. ft.

Total volume of the second-stage lagoon will be 146,630 cu. ft.

Table 3-1. Once-a-year dewatering lagoon volume in Iowa except for northwest region.
Volatile solids production < 6,000 lb. per day

	Cubic Feet Per Pound of Body Weight										
	Single-stage Lagoon					Two-stage Lagoon					
						First Stage			Second Stage		
Animal Type	Minimum Design Volume	Manure Storage Volume	Dilution Volume	Sludge Volume	Total Volume	Minimum Design Volume	Sludge Volume	Total Volume	Manure Storage Volume	Dilution Volume	Total Volume
Swine											
Nursery pig	1.70	0.42	0.85	0.40	3.37	1.70	0.40	2.10	0.32	0.85	1.27
Growing pig	[illegible]	0.39	0.85	0.40	2.93	1.69	0.40	2.09	0.39	0.85	1.24
Finishing pig	1.71	0.39	0.85	0.40	3.35	1.71	0.40	2.11	0.39	0.85	1.24
Gestation sow	0.48	0.20	0.24	0.10	1.02	0.48	0.10	0.58	0.20	0.24	0.44
Sow and litter	0.87	0.35	0.44	0.20	1.85	0.87	0.20	1.07	0.35	0.44	0.79
Boar	0.48	0.20	0.24	0.10	1.02	0.48	0.10	0.58	0.20	0.24	0.44
Cattle											
Dairy	2.00	0.51	1.00	0.41	3.92	2.00	0.41	2.41	0.51	1.00	1.51
Beef	0.72	0.36	0.36	0.29	1.71	0.72	0.29	1.01	0.36	0.36	0.71
Poultry											
Layer	2.40	0.32	1.20	0.58	4.50	2.40	0.58	2.98	0.32	1.20	1.52
Broiler	3.40	0.40	1.70	0.79	6.29	3.40	0.79	4.19	0.40	1.70	2.10

Lagoon Volume Comparisons

Basin Design (Actual Design)

Variables:

Lagoon Description =	North	
Slope =	1.5000	m/m
Liquid length (LL)=	46.9392	m
Liquid width (LW)=	40.8432	m
Liquid depth (LD)=	7.8334	m
Earth basin width (EW)=	42.6720	m
Earth basin depth (ED)=	9.7536	m
Earth basin length (EL)=	48.7680	m
Freeboard (FB)=	0.6096	m

Estimated

VOLUME = 6,961.51 m^3

Basin Design (Operational)

Variables:

Lagoon Description =	North	
Slope =	1.5000	m/m
Liquid length (LL)=	43.0073	m
Liquid width (LW)=	36.9113	m
Liquid depth (LD)=	7.8334	m
Earth basin width (EW)=	42.6720	m
Earth basin depth (ED)=	9.7536	m
Earth basin length (EL)=	48.7680	m
Freeboard (FB)=	1.9202	m

Estimated

VOLUME = 5,102.71 m^3

Basin Design (Actual Design)

Variables:

Lagoon Description =	South	
Slope =	1.5000	m/m
Liquid length (LL)=	28.6712	m
Liquid width (LW)=	43.8912	m
Liquid depth (LD)=	7.7110	m
Earth basin width (EW)=	45.7200	m
Earth basin depth (ED)=	9.6320	m
Earth basin length (EL)=	30.5000	m
Freeboard (FB)=	0.6096	m

	Estimated	
VOLUME =	3,254.97	m^3

Basin Design (Operational)

Variables:

Lagoon Description =	South	
Slope =	1.5000	m/m
Liquid length (LL)=	24.7393	m
Liquid width (LW)=	39.9593	m
Liquid depth (LD)=	7.7110	m
Earth basin width (EW)=	45.7200	m
Earth basin depth (ED)=	9.6320	m
Earth basin length (EL)=	30.5000	m
Freeboard (FB)=	1.9202	m

Estimated

VOLUME = 1,875.53 m^3

APPENDIX B: Waste Characterization of Monitoring Well Samples

Monitoring Well Data

Monitoring Well #1

SITE NAME	DATE	DATE	TIME	M-FECAL	NO3-N	AMMON-N	ORGAN-N	TOC	Geol. Lab FL	Geol. Lab CL	Geol. Lab HPO4	Geol. Lab SO4	Geol. Lab BR
				or less than					UHL Lab	UHL Lab	UHL Lab	UHL Lab	UHL Lab
K01	10/19/93	34261	1540	100	25	0.10	0.8	--					
K01	12/3/93	34306	1030	10	27	0.10	0.5	--	0.21	31.86	0.15	63.32	0.06
K01	1/25/94	34359	1420	10	27	0.20	0.1	--	0.23	30.9	0.15	61.18	0.06
K01	2/28/94	34393	930	10	21	0.10	0.1	--	0.5	27	0.5	56	0.5
K01	3/29/94	34422	1405	10	23	0.10	--	--	0.12	31.02	0.15	63.1	0.06
K01	4/26/94	34450	1825	10	24	0.20	--	--	0.12	30.09	0.15	62.02	0.06
K01	5/17/94	34471	1930	10	25	0.10	--	1	0.23	28.61	0.15	59.67	0.06
K01	6/30/94	34515	1855	10	24	0.20	--	--	0.22	28.04	0.6	61.6	0.24
K01	7/28/94	34543	1540	100	26	0.10			0.16	28.27	0.6	60.22	0.24
K01	8/24/94	34570	1825	5	24	0.10				27			
K01	9/15/94	34592	1350	10	23	0.10				25			
K01	10/13/94	34620	1315	10	22	0.10				27			
K01	11/16/94	34654	950	10	25	0.10		2.7	0.5	28	0.5	50	0.5
K01	12/13/94	34681	845	2	23	0.10	0.1			24			
K01	1/25/95	34724	825	2	21	0.20				28			
K01	2/20/95	34750	1330	2	24	0.10		1.1	0.5	27		54	0.5
K01	3/27/95	34785	1225	2	20	0.10				23			
K01	4/20/95	34809	925	2	22	0.10				28			
K01	5/24/95	34843	2025	2	23	0.10		16	0.5	29	0.5	90	0.5
K01	6/21/95	34871	920	2	16	0.10				24			
K01	7/18/95	34898	2055	2	16	0.10	0.2			24			
K01	8/15/95	34926	1950	2	20	0.10		1.1	0.5	26	0.5	76	0.5
K01	9/21/95	34963	1850	2	21	0.10	0.1		0.5	27	0.5	74	0.5
K01	10/17/95	34989	740	2	17	0.10	0.1			25			
K01	12/13/95	35046	1500	2	17	0.10				26			
K01	1/11/96	35075	900	2	21	0.10		33	0.5	27	0.5	67	0.5
K01	2/20/96	35115	1330	2	17	0.10				22			
K01	3/20/96	35144	1410	2	21	0.10				24			
K01	4/9/96	35164	1930	2	21	0.10	0.1			35			
K01	5/20/96	35205	2020	2	20	0.10			0.65	24	0.5	80	0.5
K01	6/11/96	35227	740	2	12	0.10				18			
K01	7/24/96	35270	1435	2	14	0.10	0.1	2.7		21			
K01	8/20/96	35297	2000	2	15	0.10				20			
K01	9/24/96	35332	935	2	15	0.10			0.5	23	0.5	78	0.5
K01	10/30/96	35368	1530	2	17	0.10				23			
K01	12/18/96	35417	800	2	16	0.10		1.2	0.5	23	0.5	67	0.5
K01	3/26/97	35515	15:45	2	17	0.10	17	2.1	0.5	24	0.5	75	0.5

SITE NAME	DATE	Total Calcium	Total Magnesium	Total Potassium	Nitrate-N/ Chloride ratio	Total Sodium	H20 LEVEL	(FEET) H20 READING	(FEET) CASING HT.
K01	10/19/93						10.18	10.98	0.80
K01	12/3/93				0.847		11.6	12.4	0.80
K01	1/25/94				0.874		12.78	13.58	0.80
K01	2/28/94				0.778		12.22	13.02	0.80
K01	3/29/94				0.741		12	12.8	0.80
K01	4/26/94				0.798		12.6	13.4	0.80
K01	5/17/94				0.874		11.26	12.06	0.80
K01	6/30/94				0.856		11.62	12.42	0.80
K01	7/28/94				0.920		11.88	12.68	0.80
K01	8/24/94				0.889		14.1	14.9	0.80
K01	9/15/94				0.920		13.54	14.34	0.80
K01	10/13/94				0.815		14.32	15.12	0.80
K01	11/16/94				0.893		15.18	15.98	0.80
K01	12/13/94				0.958		15.02	15.82	0.80
K01	1/25/95				0.750				
K01	2/20/95				0.889		14.82	15.62	0.80
K01	3/27/95				0.870		14.08	14.88	0.80
K01	4/20/95				0.786		8.6	9.4	0.80
K01	5/24/95				0.793		7.84	8.64	0.80
K01	6/21/95				0.667		9.09	9.89	0.80
K01	7/18/95				0.667		9.4	10.2	0.80
K01	8/15/95	120	28	1	0.769	22	10.96	11.76	0.80
K01	9/21/95				0.778		12.88	13.68	0.80
K01	10/17/95				0.680		13.54	14.34	0.80
K01	12/13/95				0.654		13.52	14.32	0.80
K01	1/11/96				0.778		14.19	14.99	0.80
K01	2/20/96				0.773		13.90	14.70	0.80
K01	3/20/96				0.875		14.18	14.98	0.80
K01	4/9/96				0.600		14.62	15.42	0.80
K01	5/20/96				0.833		8.88	9.68	0.80
K01	6/11/96				0.667		7.34	8.14	0.80
K01	7/24/96				0.667		10.12	10.92	0.80
K01	8/20/96				0.750		9.42	10.22	0.80
K01	9/24/96				0.652		11.10	11.90	0.80
K01	10/30/96				0.739		10.48	11.28	0.80
K01	12/18/96				0.696		10.27	11.07	0.80
K01	3/26/97				0.708				
						Average =	11.92943	12.72943	0.80

Monitoring Well #2

SITE NAME	DATE	DATE	TIME	M-FECAL	NO3-N	AMMON-N	ORGAN-N	TOC	Geol. Lab FL	Geol. Lab CL	Geol. Lab HPO4	Geol. Lab SO4	Geol. Lab BR
				or less than					UHL Lab	UHL Lab	UHL Lab	UHL Lab	UHL Lab
K02	10/19/93	34261	1415	20	1.5	0.1	1.3	--					
K02	12/3/93	34306	1050	10	0.8	0.1	0.6	--	0.11	23.4	0.15	49.09	0.06
K02	1/25/94	34359	1445	10	0.6	0.1	0.1	--	0.19	26.07	0.15	49.75	0.06
K02	2/28/94	34393	1010	10	0.8	0.1	0.2	--	0.5	26	0.5	52	0.5
K02	3/29/94	34422	1430	10	1.5	0.2	--	--	0.13	27.05	0.15	52.13	0.06
K02	4/26/94	34450	1845	10	1.9	0.4	--	--	0.22	28.56	0.15	56.39	0.06
K02	5/17/94	34471	1950	10	1.8	0.1	--	1.5	0.2	27.5	0.15	51.39	0.06
K02	6/30/94	34515	1915	10	1	1.6	--	--	0.16	27.43	0.6	52.23	0.24
K02	7/28/94	34543	1605	100	0.7	1.2			0.21	27.39	0.6	50.5	0.24
K02	8/24/94	34570	940	43	0.9	1.1				27			
K02	9/15/94	34592	1415	10	0.7	0.3				27			
K02	10/13/94	34620	1335	10	0.7	0.5				28			
K02	11/16/94	34654	1020	10	1.2	0.1		3.2	0.5	34	0.5	46	0.5
K02	12/13/94	34681	905	2	1.1	0.2	0.4			29			
K02	1/25/95	34724	910	2	1.2	0.1				33			
K02	2/20/95	34750	1355	2	1.4	0.1		7.2		36	0.5	53	0.5
K02	3/27/95	34785	1245	2	1.3	0.1				35			
K02	4/20/95	34809	935	2	0.9	0.1				32			
K02	5/24/95	34843	2045	2	1.6	0.1		200	0.5	38	0.5	54	0.5
K02	6/21/95	34871	1000	4	1	0.4				35			
K02	7/18/95	34898	2110	66	0.3	0.6	0.5			36			
K02	8/15/95	34926	2005	12	0.5	0.6		120	0.5	38	0.5	46	0.5
K02	9/21/95	34963	1905	2	0.5	0.2			0.5	39	0.5	48	0.5
K02	10/17/95	34989	755	2	0.1	0.1	0.2			41			
K02	12/13/95	35046	1515	2	0.1	0.1				54			
K02	1/11/96	35075	945	2	0.2	0.1		24	0.5	69	0.5	46	0.5
K02	2/20/96	35115	1345	2	0.1	0.1				88			
K02	3/20/96	35144	1425	2	0.1	0.1				85			
K02	4/9/96	35164	1945	2	0.1	0.1	0.3			90			
K02	5/20/96	35205	2045	86	0.1	0.1			0.5	82	0.5	37	0.5
K02	6/11/96	35227	735	7	0.1	0.1				89			
K02	7/24/96	35270	1500	2	0.2	0.1	0.2	320		84			
K02	8/20/96	35297	2015	2	0.1	0.1				82			
K02	9/24/96	35332	920	2	0.2	0.1			0.5	93	0.5	36	0.5
K02	10/30/96	35368	1550	2	0.1	0.1				120			
K02	12/18/96	35417	810	2	0.5	0.1		6.7	0.5	140	0.5	30	0.5
K02	3/26/97	35515	15:50	2	0.5	0.1	0.1	6.9	0.5	120	0.5	29	0.52

SITE NAME	DATE	Total Calcium	Total Magnesium	Total Potassium	Nitrate-N/ Chloride ratio	Total Sodium	H20 LEVEL	(FEET) H20 READING	(FEET) CASIN G HT.
K02	10/19/93						4.68	6.76	2.08
K02	12/3/93				0.034		3.42	5.5	2.08
K02	1/25/94				0.023		4.22	6.3	2.08
K02	2/28/94				0.031		3.52	5.6	2.08
K02	3/29/94				0.055		3.56	5.64	2.08
K02	4/26/94				0.067		4.32	6.4	2.08
K02	5/17/94				0.065		4.06	6.14	2.08
K02	6/30/94				0.036		4.08	6.16	2.08
K02	7/28/94				0.026		4.08	6.16	2.08
K02	8/24/94				0.033		4.4	6.48	2.08
K02	9/15/94				0.026		4.4	6.48	2.08
K02	10/13/94				0.025		4.48	6.56	2.08
K02	11/16/94				0.035		4.38	6.46	2.08
K02	12/13/94				0.038		4.26	6.34	2.08
K02	1/25/95				0.036				
K02	2/20/95				0.039		4.58	6.66	2.08
K02	3/27/95				0.037		4	6.08	2.08
K02	4/20/95				0.028				
K02	5/24/95				0.042		2.86	4.94	2.08
K02	6/21/95				0.029		4.01	6.09	2.08
K02	7/18/95				0.008		4.18	6.26	2.08
K02	8/15/95	120	30	1.0	0.013	11	4.72	6.8	2.08
K02	9/21/95				0.013		4.86	6.94	2.08
K02	10/17/95				0.002		4.90	6.98	2.08
K02	12/13/95				0.002		4.72	6.8	2.08
K02	1/11/96				0.003		4.81	6.89	2.08
K02	2/20/96				0.001		4.78	6.86	2.08
K02	3/20/96				0.001		4.72	6.8	2.08
K02	4/9/96				0.001		4.72	6.8	2.08
K02	5/20/96				0.001				
K02	6/11/96				0.001		3.02	5.1	2.08
K02	7/24/96				0.002		5.64	7.72	2.08
K02	8/20/96				0.001		4.65	6.73	2.08
K02	9/24/96				0.002		5.04	7.12	2.08
K02	10/30/96				0.001		4.10	6.18	2.08
K02	12/18/96				0.004		4.22	6.3	2.08
K02	3/26/97				0.004				
						Average =	4.314848	6.394848	2.08

Monitoring Well #3

SITE NAME	DATE	DATE	TIME	M-FECAL	NO3-N	AMMON-N	ORGAN-N	TOC	Geol. Lab FL	Geol. Lab CL	Geol. Lab HPO4	Geol. Lab SO4	Geol. Lab BR
				or less than					UHL Lab	UHL Lab	UHL Lab	UHL Lab	UHL Lab
K03	10/19/93	34261	1425	80	9.2	0.1	0.7	--					
K03	12/3/93	34306	1100	10	11	0.1	0.3	--	0.24	34.46	0.15	49.29	0.06
K03	1/25/94	34359	1435	10	9.4	0.2	0.1	--	0.21	33.06	0.15	50.7	0.06
K03	2/28/94	34393	950	10	7.2	0.1	0.1	--	0.5	32	0.5	48	0.5
K03	3/29/94	34422	1420	10	7.2	0.1	--	--	0.25	33.06	0.15	52.39	0.06
K03	4/26/94	34450	1835	10	6.4	0.5	--	--	0.17	35.25	0.15	52.23	0.06
K03	5/17/94	34471	1940	10	6.1	0.2	--	1.1	0.11	34.33	0.15	50.52	0.06
K03	6/30/94	34515	1905	10	5.4	0.2	--	--	0.21	32.35	0.6	52.36	0.24
K03	7/28/94	34543	1555	100	6	0.1			0.19	34.55	0.6	52.21	0.24
K03	8/24/94	34570	925	5	5.8	0.1				37			
K03	9/15/94	34592	1400	10	6	0.1				31			
K03	10/13/94	34620	1325	10	5.9	0.1				32			
K03	11/16/94	34654	1010	10	5.7	0.1		1.6	0.5	35	0.5	47	0.5
K03	12/13/94	34681	855	2	5.2	0.2	0.3			31			
K03	1/25/95	34724	855	2	4.3	0.1				36			
K03	2/20/95	34750	1345	2	3.8	0.1		6.6	0.5	41	0.5	47	0.5
K03	3/27/95	34785	1235	2	3.3	0.1				41			
K03	4/20/95	34809	945	2	3	0.1				45			
K03	5/24/95	34843	2035	2	2.4	0.1		98	0.5	41	0.5	44	0.5
K03	6/21/95	34871	1015	2	1.9	0.1				33			
K03	7/18/95	34898	2105	2	1.6	0.1	0.2			37			
K03	8/15/95	34926	2000	2	1.6	0.1		71	0.5	48	0.5	45	0.5
K03	9/21/95	34963	1910	4	1.5	0.1			0.5	58	0.5	41	0.5
K03	10/17/95	34989	750	2	1.0	0.1	0.2			66			
K03	12/13/95	35046	1510	2	0.4	0.1				88			
K03	1/11/96	35075	935	2	0.3	0.1		80	0.5	97	0.5	30	0.5
K03	2/20/96	35115	1340	2	0.2	0.1				120			
K03	3/20/96	35144	1420	2	0.2	0.1				110			
K03	4/9/96	35164	1940	2	0.1	0.1	0.6			120			
K03	5/20/96	35205	2035	54	0.1	0.1			0.5	120	0.5	26	0.5
K03	6/11/96	35227	750	3	0.1	0.1				94			
K03	7/24/96	35270	1450	2	0.1	0.1	0.3	160		86			
K03	8/20/96	35297	2010	2	0.1	0.1				98			
K03	9/24/96	35332	1010	2	0.1	0.1			0.5	110	0.5	29	0.5
K03	10/30/96	35368	1545	2	0.1	0.1				160			
K03	12/18/96	35417	815	2	0.5	0.1		8.7	0.5	190	0.5	21	0.5
K03	3/26/97	35515	15:55	2	0.5	0.2	0.1	14	0.5	150	0.5	24	0.5

SITE NAME	DATE	Total Calcium	Total Magnesium	Total Potassium	Nitrate-N/ Chloride ratio	Total Sodium	H20 LEVEL	(FEET) H20 READING	(FEET) CASING HT.
K03	10/19/93						1.82	4.3	2.48
K03	12/3/93				0.319		2.04	4.52	2.48
K03	1/25/94				0.284		2.82	5.3	2.48
K03	2/28/94				0.225		2.51	4.99	2.48
K03	3/29/94				0.218		2.64	5.12	2.48
K03	4/26/94				0.182		2.96	5.44	2.48
K03	5/17/94				0.178		3.22	5.7	2.48
K03	6/30/94				0.167		3.34	5.82	2.48
K03	7/28/94				0.174		3.34	5.82	2.48
K03	8/24/94				0.157		3.62	6.1	2.48
K03	9/15/94				0.194		3.62	6.1	2.48
K03	10/13/94				0.184		3.72	6.2	2.48
K03	11/16/94				0.163		3.78	6.26	2.48
K03	12/13/94				0.168		3.86	6.34	2.48
K03	1/25/95				0.119				
K03	2/20/95				0.093		4.48	6.96	2.48
K03	3/27/95				0.080		3.96	6.44	2.48
K03	4/20/95				0.067		2.48	4.96	2.48
K03	5/24/95				0.059		2.52	5.00	2.48
K03	6/21/95				0.058		3.74	6.22	2.48
K03	7/18/95				0.043		3.94	6.42	2.48
K03	8/15/95	130	34	1	0.033	11	4.48	6.96	2.48
K03	9/21/95				0.026		4.76	7.24	2.48
K03	10/17/95				0.015		4.86	7.34	2.48
K03	12/13/95				0.005		4.92	7.40	2.48
K03	1/11/96				0.003		4.86	7.34	2.48
K03	2/20/96				0.002		5.16	7.64	2.48
K03	3/20/96				0.002		5.08	7.56	2.48
K03	4/9/96				0.001		4.62	7.10	2.48
K03	5/20/96				0.001		3.32	5.80	2.48
K03	6/11/96				0.001		2.84	5.32	2.48
K03	7/24/96				0.001		4.92	7.40	2.48
K03	8/20/96				0.001		5.16	7.64	2.48
K03	9/24/96				0.001		5.44	7.92	2.48
K03	10/30/96				0.001		4.96	7.44	2.48
K03	12/18/96				0.003		4.52	7.00	2.48
K03	3/26/97				0.003				
						Average =	3.837429	6.317429	2.48

Monitoring Well #4

SITE NAME	DATE	DATE	TIME	M-FECAL	NO3-N	AMMON-N	ORGAN-N	TOC	Geol. Lab FL	Geol. Lab CL	Geol. Lab HPO4	Geol. Lab SO4	Geol. Lab BR
				or less than					UHL Lab	UHL Lab	UHL Lab	UHL Lab	UHL Lab
K04	10/19/93	34261	1430	10	1	0.4	0.7	--					
K04	12/3/93	34306	1040	10	0.1	1	1.1	--	0.04	42.52	0.15	22.66	0.06
K04	1/25/94	34359	1430	10	0.1	0.7	0.4	--	0.1	44.61	0.15	13.42	0.06
K04	2/28/94	34393	945	10	0.5	0.5	0.1	--	0.5	41	0.5	11	0.5
K04	3/29/94	34422	1415	10	0.1	0.4	--	--	0.24	46.69	0.15	12.27	0.06
K04	4/26/94	34450	1830	10	0.1	0.6	--	--	0.15	50.02	0.15	13.08	0.06
K04	5/17/94	34471	1935	10	0.1	0.4	--	3.1	0.19	49.33	0.15	11.85	0.06
K04	6/30/94	34515	1900	10	0.1	0.3	--	--	0.16	48.28	0.6	13.68	0.24
K04	7/28/94	34543	1550	100	0.1	0.3			0.19	50.8	0.6	11.03	0.24
K04	8/24/94	8/24/94	950	5	0.1	0.3				50			
K04	9/15/94	34592	1355	10	0.1	0.5				74			
K04	10/13/94	34620	1320	10	0.1	0.4				80			
K04	11/16/94	34654	1030	10	0.5	0.2		8.5	0.5	78	0.5	6.7	0.5
K04	12/13/94	34681	850	2	0.1	0.5	0.7			83			
K04	1/25/95	34724	840	2	0.1	0.3				91			
K04	2/20/95	34750	1340	2	0.50	0.1		170	0.5	97	0.5	15	0.7
K04	3/27/95	34785	1230	2	0.10	0.2				100			
K04	4/20/95	34809	955	2	0.10	0.6				110			
K04	5/24/95	34843	2030	2	0.50	0.9		380	0.5	100	0.5	11	0.5
K04	6/21/95	34871	935	2	0.10	0.3				130			
K04	7/18/95	34898	2100	2	0.10	0.5	3.3			160			
K04	8/15/95	34926	1955	2	0.50	0.5		120	4.1	130	0.5	7.8	0.5
K04	9/21/95	34963	1900	2	0.50	0.3	2.0		2.9	150	0.5	7.6	0.5
K04	10/17/95	34989	745	2	0.10	0.1	1.9			170			
K04	12/13/95	35046	1505	2	0.10	0.1				220			
K04	1/11/96	35075	920	2	0.10	0.2		48	2	190	0.5	4.4	0.5
K04	2/20/96	35115	1335	2	0.10	0.2				200			
K04	3/20/96	35144	1415	2	0.10	0.1				200	0.8	3.3	
K04	4/9/96	35164	1935	2	0.10	0.2	2.3			220			
K04	5/20/96	35205	2030	2	0.10	0.1			0.55	190	0.5	6.3	0.5
K04	6/11/96	35227	745	2	0.10	0.2				200			
K04	7/24/96	35270	NA	2	0.10	0.4	1.8	270		240			
K04	8/20/96	35297	2005	20	0.10	0.4				260			
K04	9/24/96	35332	1000	2	0.10	0.5			0.5	260	0.5	3.7	0.5
K04	10/30/96	35368	1535	2	0.10	0.6				310			
K04	12/18/96	35417	820	2	0.50	0.7		42	0.5	340	0.5	3.0	0.5
K04	3/26/97	35515	16:00	2	0.50	1	0.1	29	0.54	330	0.5	2.8	0.89

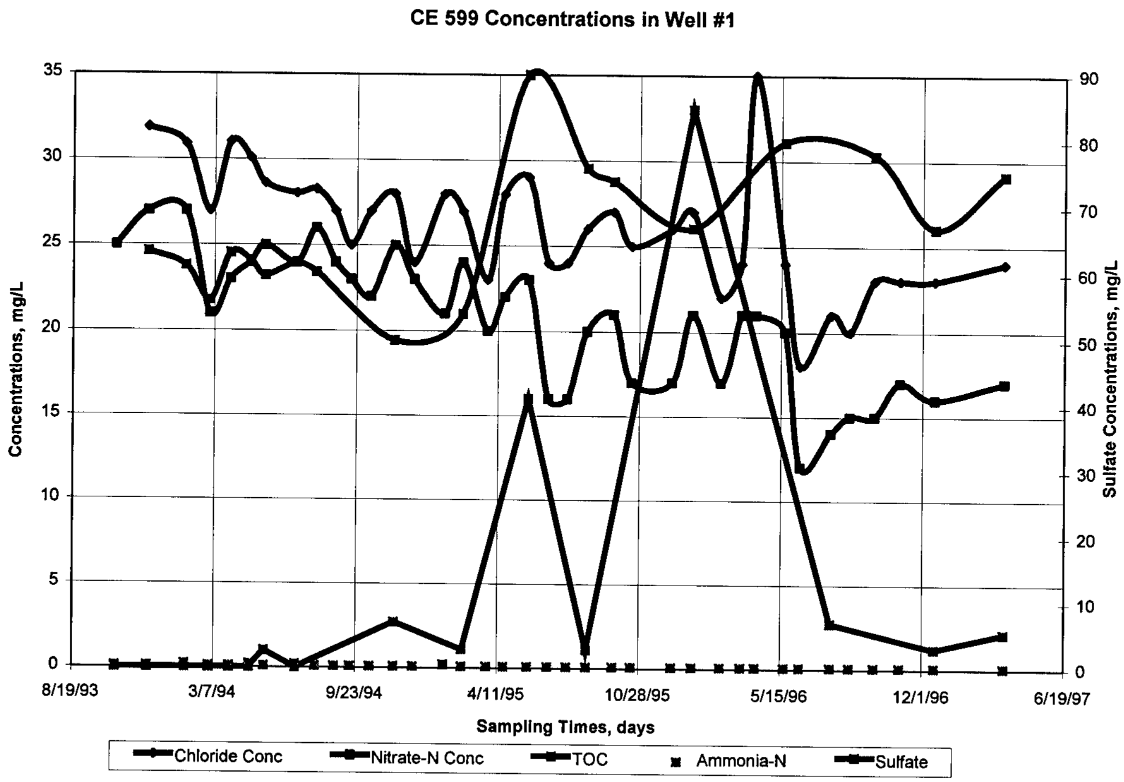
SITE NAME	DATE	Total Calcium	Total Magnesium	Total Potassium	Nitrate-N/ Chloride ratio	Total Sodium	H20 LEVEL	(FEET) H20 READING	(FEET) CASING HT.
K04	10/19/93						9.83	11.83	2.00
K04	12/3/93				0.002		10.92	12.92	2.00
K04	1/25/94				0.002		11.48	13.48	2.00
K04	2/28/94				0.012		11.92	13.92	2.00
K04	3/29/94				0.002		12.38	14.38	2.00
K04	4/26/94				0.002		12.4	14.4	2.00
K04	5/17/94				0.002		12.84	14.84	2.00
K04	6/30/94				0.002		12.63	14.63	2.00
K04	7/28/94				0.002		12.38	14.38	2.00
K04	8/24/94				0.002		12.44	14.44	2.00
K04	9/15/94				0.001		12.36	14.36	2.00
K04	10/13/94				0.001		12.45	14.45	2.00
K04	11/16/94				0.006		12.65	14.65	2.00
K04	12/13/94				0.001		12.82	14.82	2.00
K04	1/25/95				0.001				
K04	2/20/95				0.005		13.54	15.54	2.00
K04	3/27/95				0.001		13.78	15.78	2.00
K04	4/20/95				0.001		12.88	14.88	2.00
K04	5/24/95				0.005		12.64	14.64	2.00
K04	6/21/95				0.001		12.98	14.98	2.00
K04	7/18/95				0.001		13.2	15.2	2.00
K04	8/15/95	260	70	2.4	0.004	25	13.58	15.58	2.00
K04	9/21/95				0.003		14.4	16.4	2.00
K04	10/17/95				0.001		14.3	16.3	2.00
K04	12/13/95				0.000		17.95	19.95	2.00
K04	1/11/96				0.001		14.28	16.28	2.00
K04	2/20/96				0.001		15.36	17.36	2.00
K04	3/20/96				0.001		15.47	17.47	2.00
K04	4/9/96				0.000		15.56	17.56	2.00
K04	5/20/96				0.001		14.04	16.04	2.00
K04	6/11/96				0.001		13.36	15.36	2.00
K04	7/24/96				0.000		15.12	17.12	2.00
K04	8/20/96				0.000		15.3	17.3	2.00
K04	9/24/96				0.000		15.46	17.46	2.00
K04	10/30/96				0.000		15.24	17.24	2.00
K04	12/18/96				0.001		15.28	17.28	2.00
K04	3/26/97				0.002				
						Average =	13.52057	15.52057	2.00

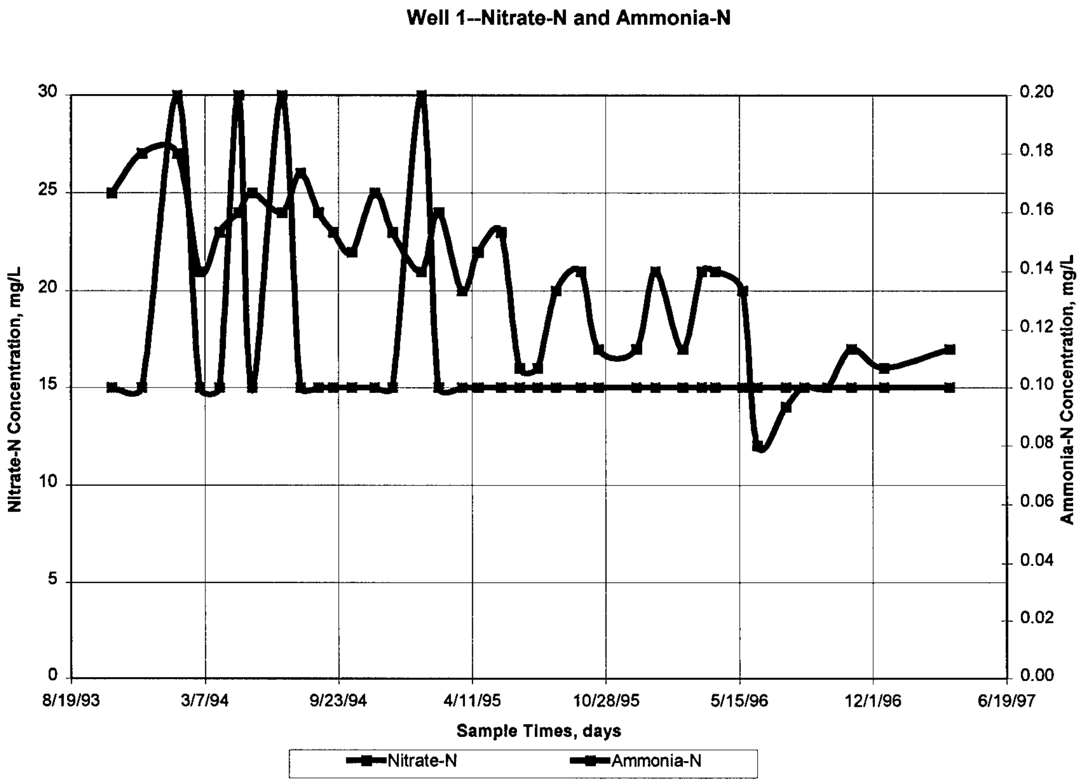
Monitoring Well #5

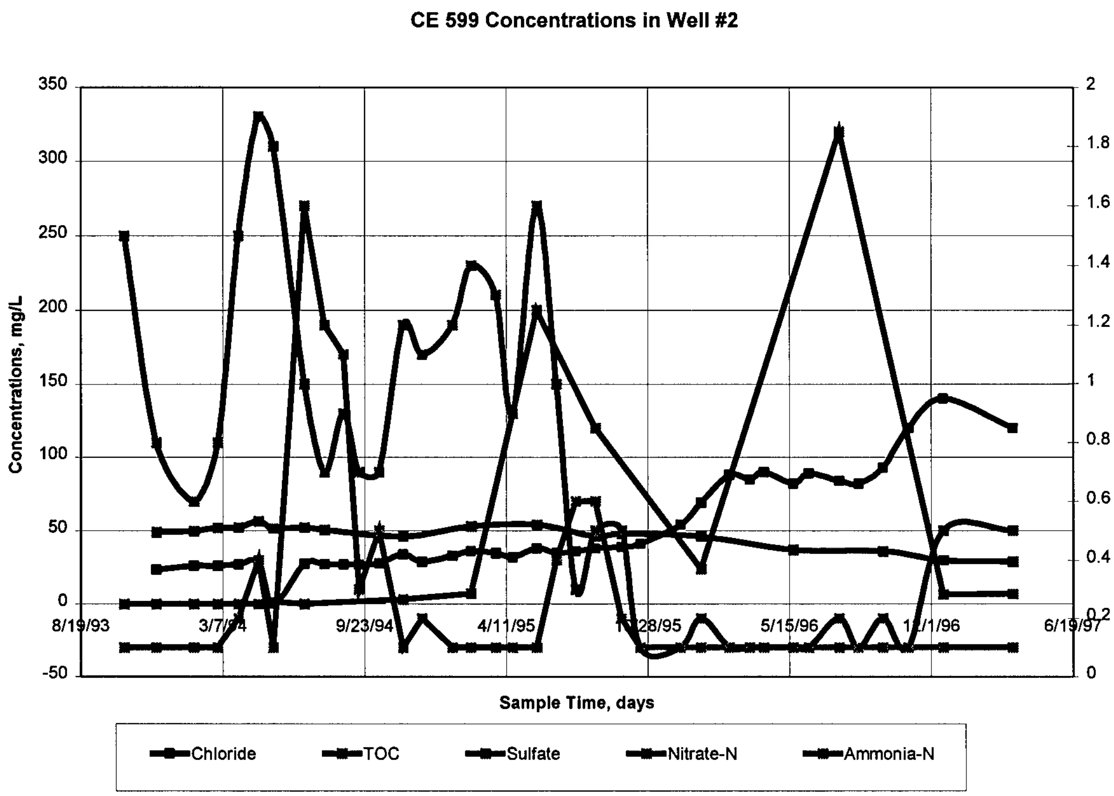
SITE NAME	DATE	DATE	TIME	M-FECAL	NO3-N	AMMON-N	ORGAN-N	TOC	Geol. Lab FL	Geol. Lab CL	Geol. Lab HPO4	Geol. Lab SO4	Geol. Lab BR
				or less than					UHL Lab	UHL Lab	UHL Lab	UHL Lab	UHL Lab
K05	10/21/93	34263	1020	320	8.4	0.1	0.5	--					
K05	12/3/93	34306	1110	10	15	0.1	1.4	--	0.26	40.25	0.15	53.76	0.06
K05	1/25/94	34359	1440	10	15	0.2	0.2	--	0.14	38.84	0.15	53.3	0.06
K05	2/28/94	34393	1005	10	12	0.1	0.1	--	0.5	34	0.5	50	0.5
K05	3/29/94	34422	1425	10	15	0.2	--	--	0.21	38.5	0.15	26.51	0.06
K05	4/26/94	34450	1640	10	14	0.2	--	--	0.17	37.44	0.15	52.37	0.06
K05	5/17/94	34471	1945	10	14	0.1	--	1.1	0.23	37.19	0.15	52.48	0.06
K05	6/30/94	34515	1910	10	13	0.2	--	--	0.16	34.88	0.6	53.05	0.24
K05	7/28/94	34543	1600	100	12	0.1			0.24	33.74	0.6	51.1	0.24
K05	8/24/94	34570	1835	5	10	0.1				30			
K05	9/15/94	34592	1410	10	8.9	0.1				32			
K05	10/13/94	34620	1330	10	7.00	0.4				31			
K05	11/16/94	34654	1015	10	8.7	0.1		2.7	0.5	33	0.5	48	0.5
K05	12/13/94	34681	900	2	8.00	0.1	0.4			27			
K05	1/25/95	34724	900	2	7.1	0.2				29			
K05	2/20/95	34750	1350	2	6.2	0.1		15	0.5	32	0.5	56	0.5
K05	3/27/95	34785	1240	2	5.4	0.1				37			
K05	4/20/95	34809	1010	2	4.4	0.1				32			
K05	5/24/95	34843	2040	2	4	0.1		540	0.5	30	0.5	51	0.5
K05	6/22/95	34872	830	2	3.4	0.2				34			
K05	7/18/95	34898	2115	2	3.0	0.1	0.1			34			
K05	8/15/95	34898	2010	2	2.4	0.1		78	0.5	36	0.5	54	0.5
K05	9/21/95	34963	1915	2	1.8	0.1			0.5	39	0.5	54	0.5
K05	10/17/95	34989	800	2	1.6	0.1	0.3			40			
K05	12/13/95	35046	1520	2	1.2	0.1				43			
K05	1/11/96	35075	955	2	1.3	0.1		290	0.5	51	0.5	58	0.5
K05	2/20/96	35115	1350	2	1.0	0.1				52			
K05	3/20/96	35144	1430	2	1	0.1				47			
K05	4/9/96	35164	1950	2	0.8	0.1	0.2			47			
K05	5/20/96	35205	2050	2	0.5	0.1			0.5	260	0.5	48	0.5
K05	6/11/96	35227	800	2	0.3	0.1				53			
K05	7/24/96	35270	NA	2	0.2	0.1	0.2	260		57			
K05	8/20/96	35297	2020	2	0.2	0.1				55			
K05	9/24/96	35332	1015	2	0.1	0.1			0.5	63	0.5	50	0.5
K05	10/30/96	35368	1555	2	0.1	0.1			0.5	60			
K05	12/18/96	35417	830	2	0.1	0.1		18	0.5	74	0.5	49	0.5
K05	3/26/97	35515	16:05	2	0.5	0.1	0.1	7.6	0.5	73	0.5	47	0.5

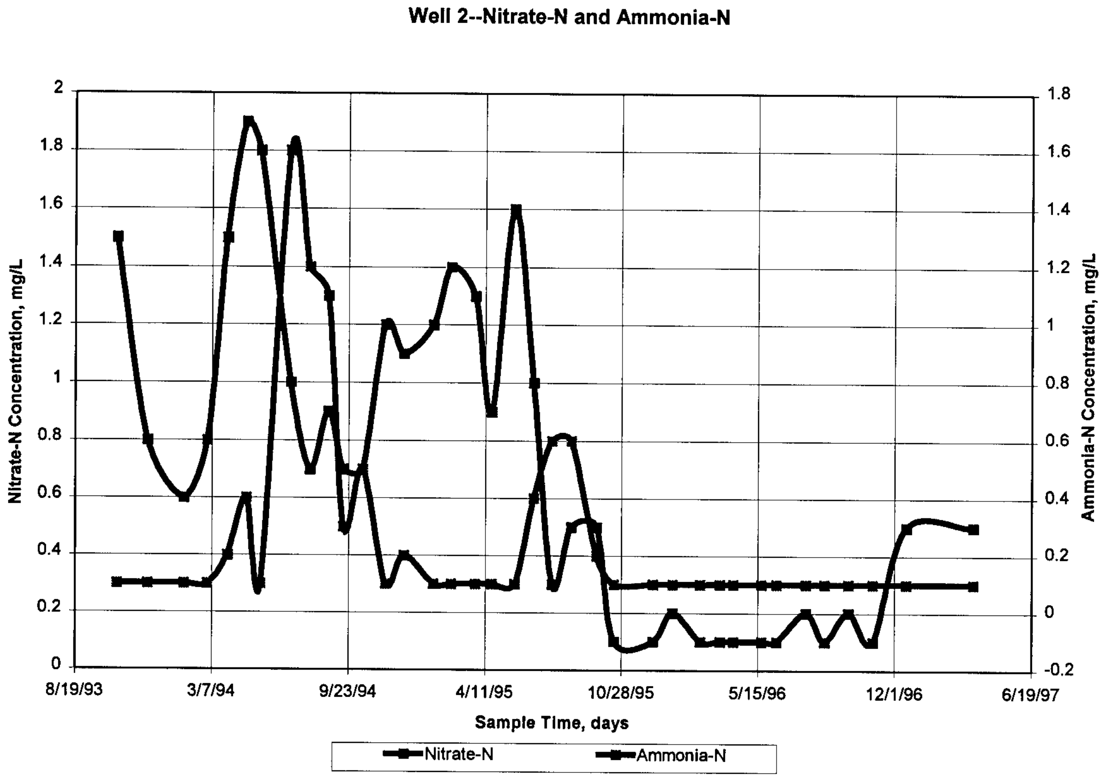
SITE NAME	DATE	Total Calcium	Total Magnesium	Total Potassium	Nitrate-N/ Chloride ratio	Total Sodium	H20 LEVEL	(FEET) H20 READING	(FEET) CASING HT.
K05	10/21/93						5.94	7.54	1.60
K05	12/3/93				0.373		3.04	4.64	1.60
K05	1/25/94				0.386		4.84	6.44	1.60
K05	2/28/94				0.353		3.82	5.42	1.60
K05	3/29/94				0.390		3.98	5.58	1.60
K05	4/26/94				0.374		4.56	6.16	1.60
K05	5/17/94				0.376		4.86	6.46	1.60
K05	6/30/94				0.373		5.54	7.14	1.60
K05	7/28/94				0.356		5.1	6.7	1.60
K05	8/24/94				0.333		5.9	7.5	1.60
K05	9/15/94				0.278		6.2	7.8	1.60
K05	10/13/94				0.226		6.44	8.04	1.60
K05	11/16/94				0.264		6.58	8.18	1.60
K05	12/13/94				0.296		6.76	8.36	1.60
K05	1/25/95				0.245				
K05	2/20/95				0.194		6.88	8.48	1.60
K05	3/27/95				0.146		6.74	8.34	1.60
K05	4/20/95				0.138		2.3	3.9	1.60
K05	5/24/95				0.133		1.8	3.4	1.60
K05	6/22/95				0.100		3.68	5.28	1.60
K05	7/18/95				0.088		4.12	5.72	1.60
K05	8/15/95	130	33	1.8	0.067	9.8	5.58	7.18	1.60
K05	9/21/95				0.046		6.7	8.3	1.60
K05	10/17/95				0.040		6.96	8.56	1.60
K05	12/13/95				0.028		7.26	8.86	1.60
K05	1/11/96				0.025		7.49	9.09	1.60
K05	2/20/96				0.019		6.74	8.34	1.60
K05	3/20/96				0.021		6.76	8.36	1.60
K05	4/9/96				0.017		7.44	9.04	1.60
K05	5/20/96				0.002		2.5	4.1	1.60
K05	6/11/96				0.006		1.55	3.15	1.60
K05	7/24/96				0.004		4.56	6.16	1.60
K05	8/20/96				0.004		2.23	3.83	1.60
K05	9/24/96				0.002		5.82	7.42	1.60
K05	10/30/96				0.002		6.38	7.98	1.60
K05	12/18/96				0.001		4.9	6.5	1.60
K05	3/26/97				0.007				
						Average =	5.198571	6.798571	1.60

MW Characteristics

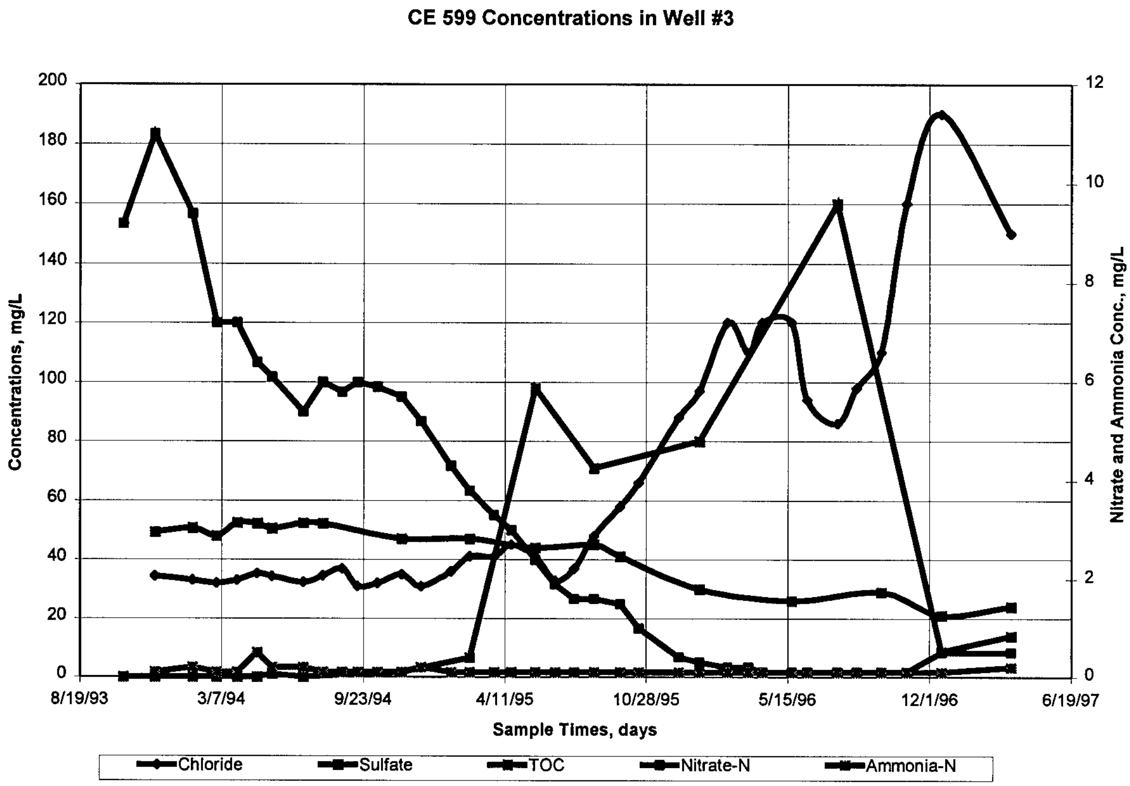



Well 1--Nitrate-N and Ammonia-N
30
25
20
15
10
5
0
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Nitrate-N Concentration, mg/L
Ammonia-N Concentration, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, days
Nitrate-N
Ammonia-N

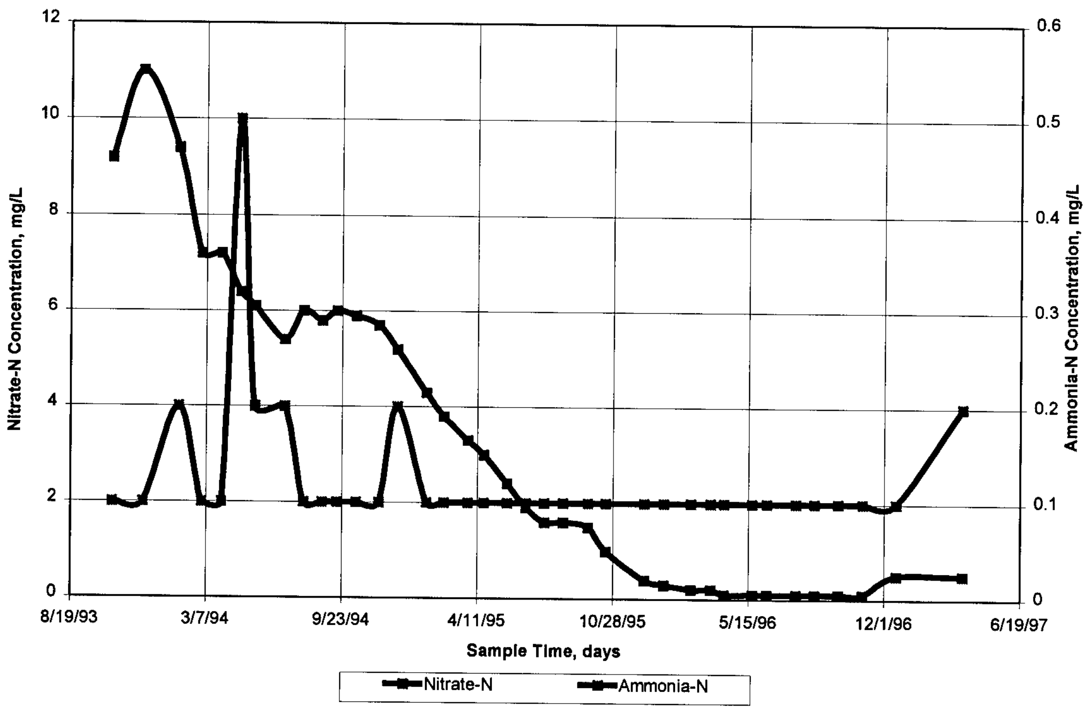

CE 599 Concentrations in Well #2
Concentrations, mg/L
Nitrate and Ammonia Conc., mg/L
350
300
250
200
150
100
50
0
-50
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Time, days
Chloride
TOC
Sulfate
Nitrate-N
Ammonia-N



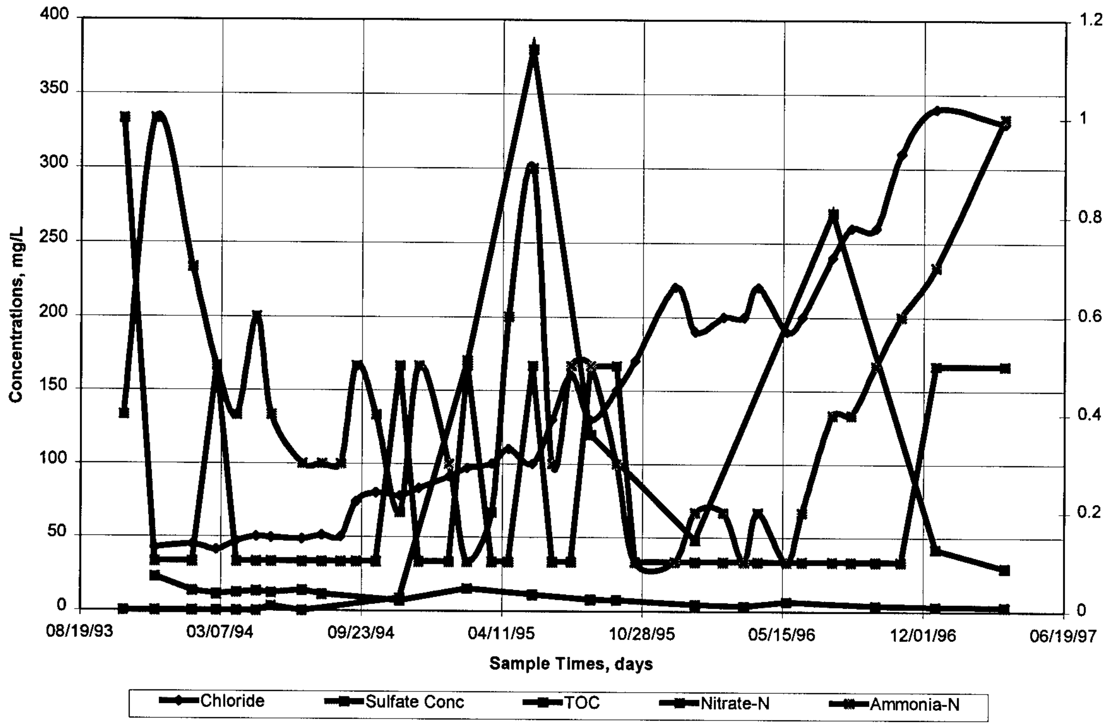
Well 2--Nitrate-N and Ammonia-N
Nitrate-N Concentration, mg/L
Ammonia-N Concentration, mg/L
Sample Time, days
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
-0.2
Nitrate-N
Ammonia-N

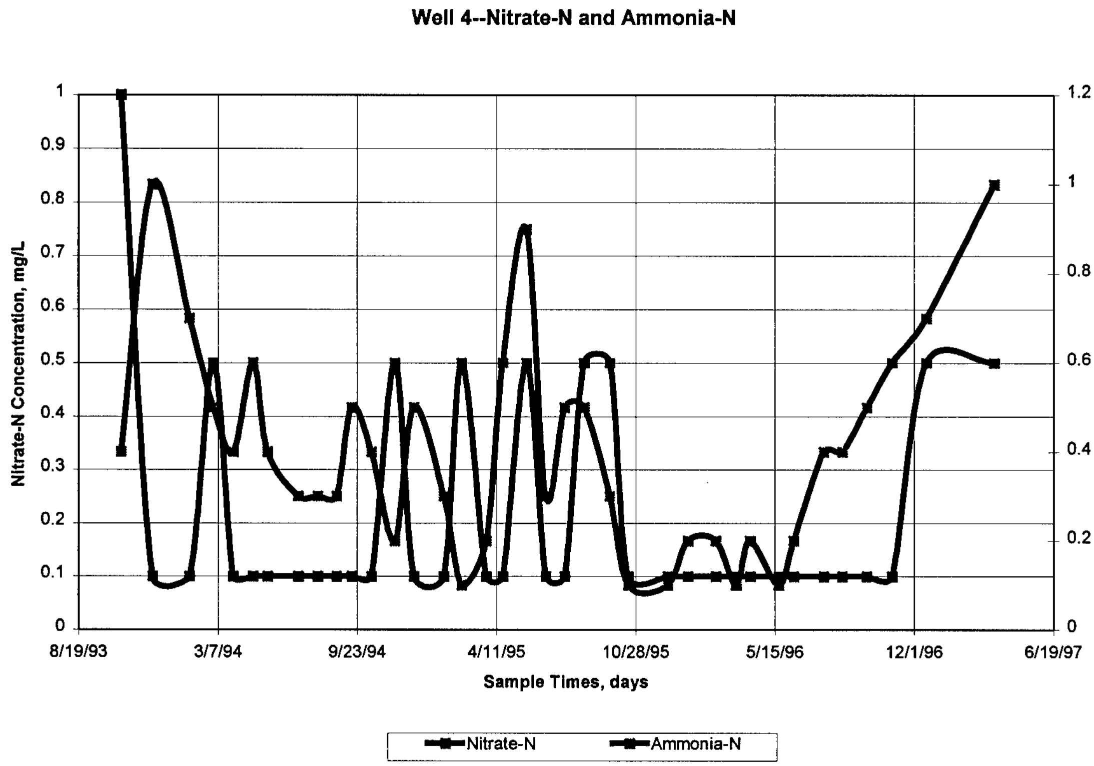

CE 599 Concentrations in Well #3
Concentrations, mg/L
200
180
160
140
120
100
80
60
40
20
0
Nitrate and Ammonia Conc., mg/L
12
10
8
6
4
2
0
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, days
Chloride
Sulfate
TOC
Nitrate-N
Ammonia-N

Well 3--Nitrate-N and Ammonia-N

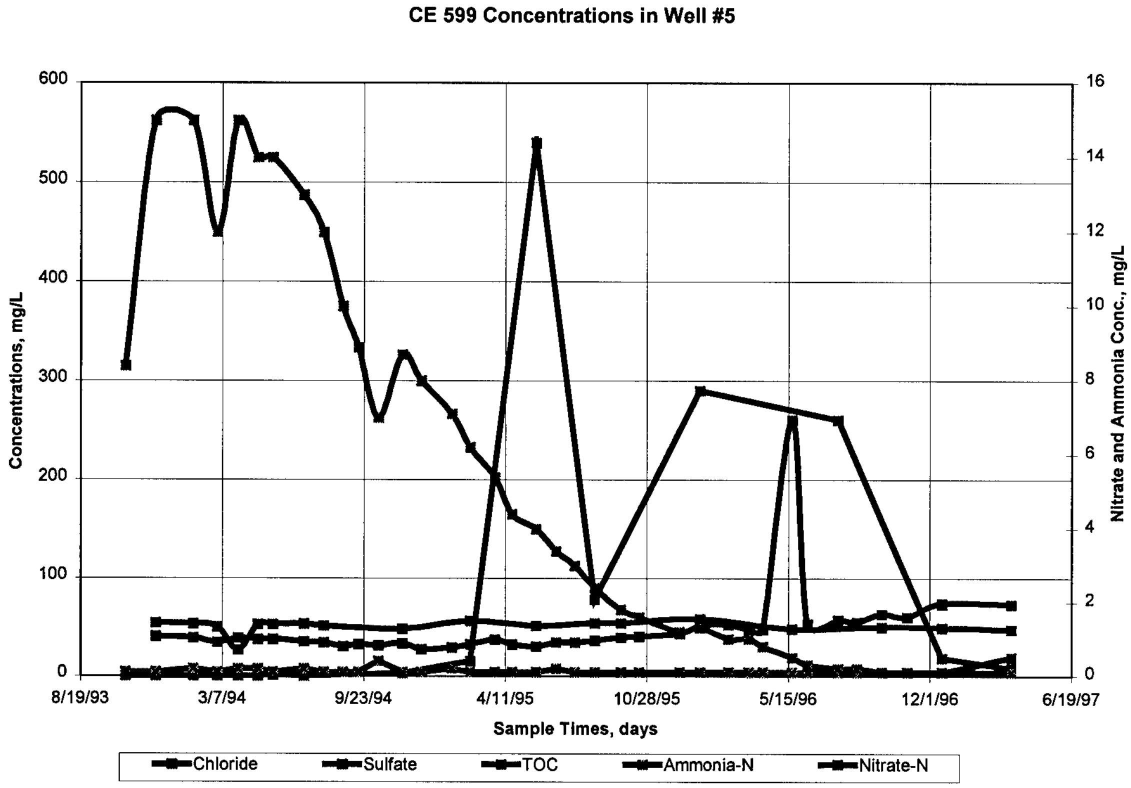


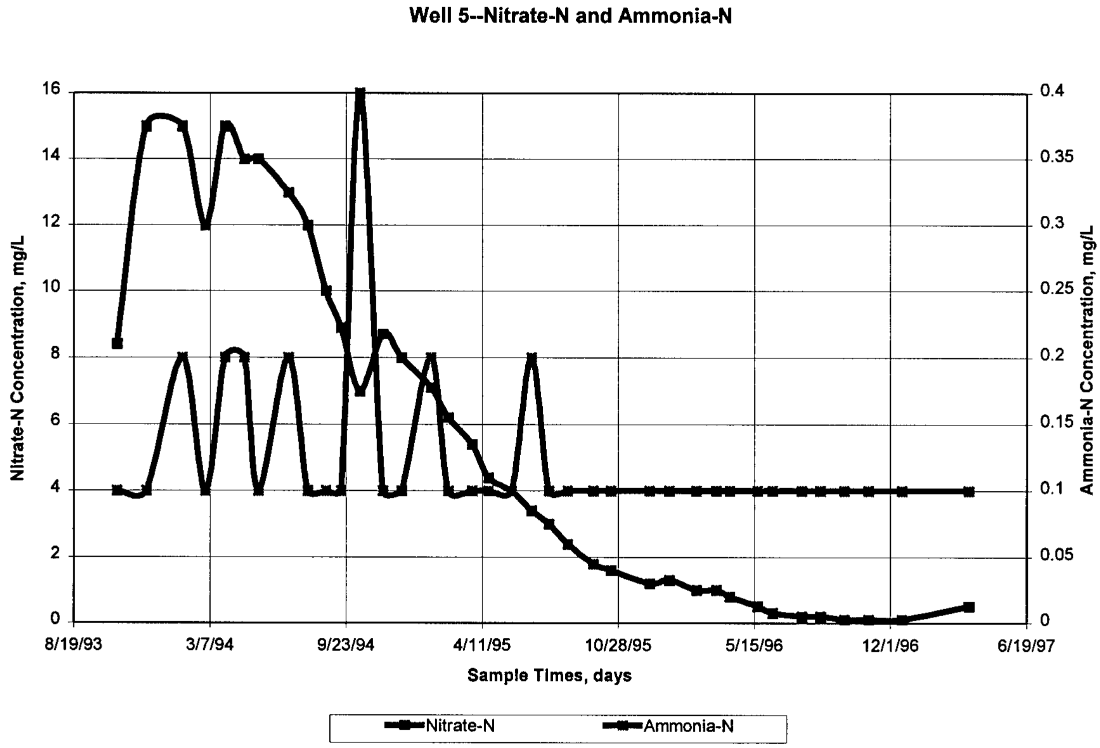
CE 599 Concentrations in Well #4





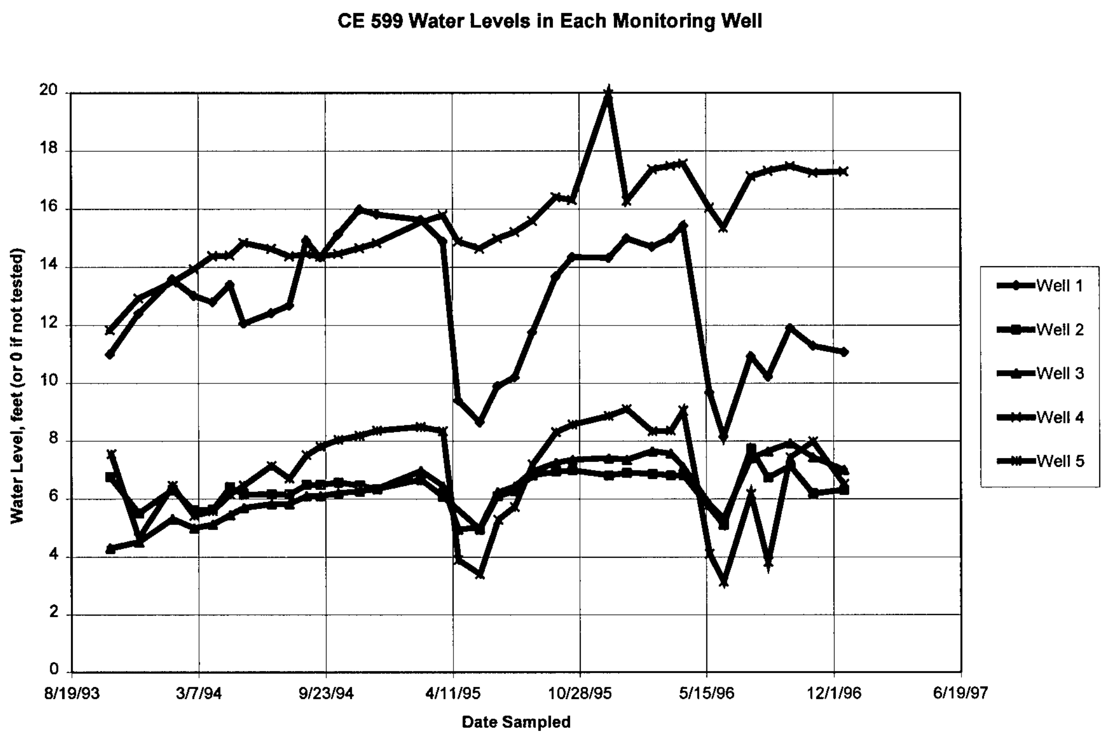
Well 4--Nitrate-N and Ammonia-N
Nitrate-N Concentration, mg/L
Ammonia-N Concentration, mg/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.2
1
0.8
0.6
0.4
0.2
0
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, days
Nitrate-N
Ammonia-N


CE 599 Concentrations in Well #5
Concentrations, mg/L
Nitrate and Ammonia Conc., mg/L
600
500
400
300
200
100
0
16
14
12
10
8
6
4
2
0
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, days
Chloride
Sulfate
TOC
Ammonia-N
Nitrate-N

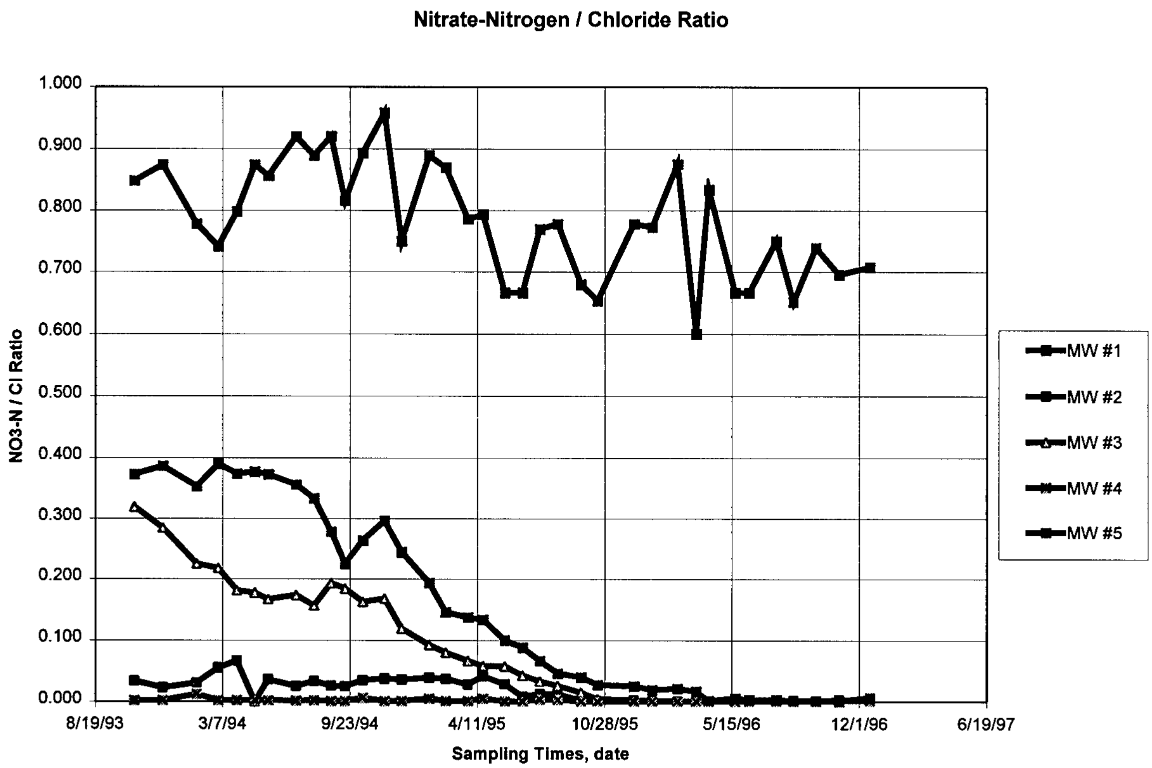


Well 5--Nitrate-N and Ammonia-N
Nitrate-N Concentration, mg/L
Ammonia-N Concentration, mg/L
16
14
12
10
8
6
4
2
0
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, days
Nitrate-N
Ammonia-N

Kirkwood MW Water Levels



Nitrate-N/Chloride Ratio



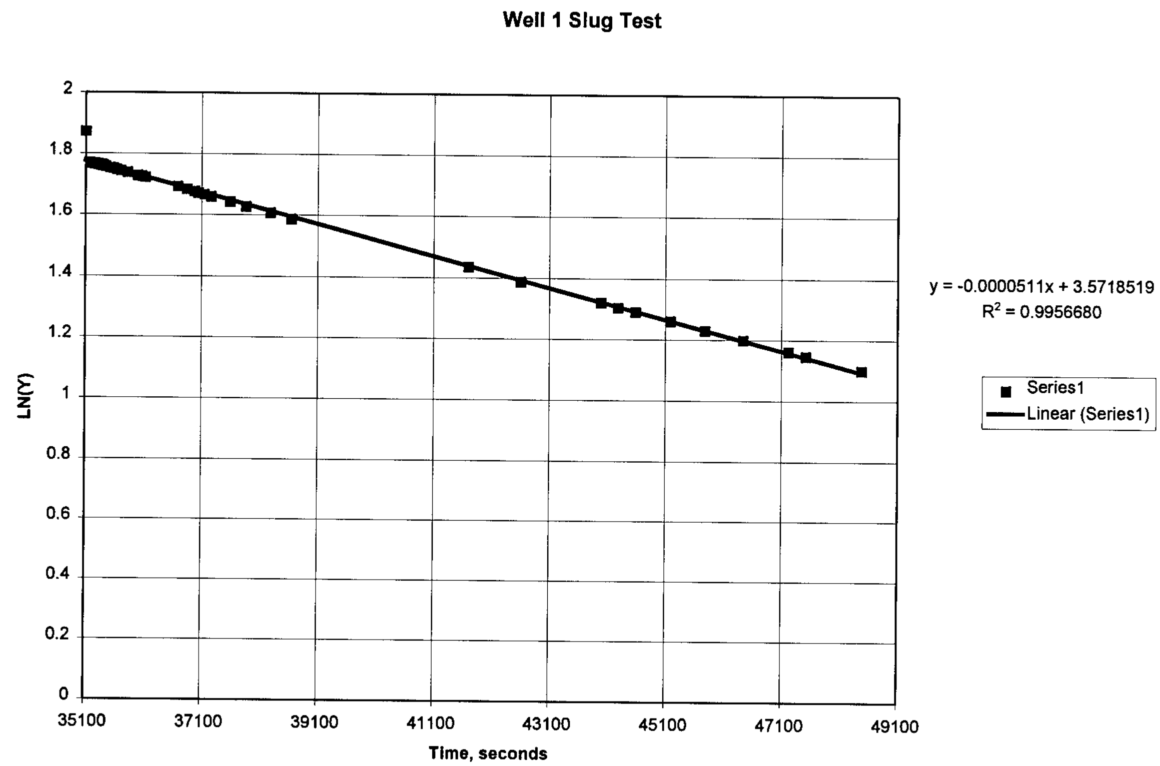
APPENDIX C: Bouwer and Rice/Hvorslev Slug Test Results

Monitoring Well Slug Test Data

Well Number =	1		
Transducer Depth =	18	feet	
Casing Height =	839.8	feet	
Initial Water Depth =	9.4	feet	*from top of casing
Water Depth after Slugging =	15.9	feet	*from top of casing
			*76.98% recovery

Time, minutes	Pressure, psi	Y, feet	Ln(Y)	Time, sec	
9:45	0.197	6.5	1.871802	35100	Initial Readings
9:46:08	1.3792	5.87034	1.769913	35168	
9:46:19	1.3802	5.868031	1.769519	35179	
9:46:39	1.3826	5.86249	1.768574	35199	
9:47:01	1.3829	5.861797	1.768456	35221	
9:47:10	1.3842	5.858796	1.767944	35230	
9:47:29	1.3862	5.854178	1.767156	35249	
9:47:41	1.3872	5.851869	1.766761	35261	
9:47:54	1.3879	5.850252	1.766485	35274	
9:48:02	1.3895	5.846558	1.765853	35282	
9:48:10	1.3905	5.844249	1.765458	35290	
9:48:24	1.3919	5.841017	1.764905	35304	
9:48:34	1.3932	5.838015	1.764391	35314	
9:48:42	1.3935	5.837322	1.764272	35322	
9:48:51	1.3945	5.835013	1.763877	35331	
9:49:01	1.3962	5.831088	1.763204	35341	
9:49:15	1.3972	5.828779	1.762808	35355	
9:49:20	1.3975	5.828086	1.762689	35360	
9:49:32	1.3995	5.823468	1.761896	35372	
9:49:41	1.3992	5.824161	1.762015	35381	
9:49:51	1.4025	5.816541	1.760706	35391	
9:50:02	1.4021	5.817465	1.760865	35402	
9:50:12	1.4031	5.815156	1.760468	35412	
9:50:20	1.4051	5.810538	1.759673	35420	
9:50:32	1.4065	5.807306	1.759117	35432	
9:50:41	1.4084	5.802919	1.758361	35441	
9:52	1.4197	5.776827	1.753855	35520	
9:53	1.4277	5.758356	1.750652	35580	
9:54	1.435	5.7415	1.747721	35640	
9:55	1.443	5.723028	1.744498	35700	
9:57	1.4589	5.686316	1.738063	35820	
10:00	1.4844	5.627437	1.727654	36000	
10:01	1.4901	5.614276	1.725313	36060	
10:02	1.4981	5.595804	1.722017	36120	

10:11:29	1.5692	5.431637	1.692241	36689
10:14	1.5894	5.384996	1.683617	36840
10:16:15	1.6047	5.349669	1.677035	36975
10:17:14	1.6183	5.318267	1.671147	37034
10:19	1.6301	5.291021	1.666011	37140
10:21	1.6455	5.255463	1.659268	37260
10:26:24	1.6819	5.171416	1.643147	37584
10:31	1.7151	5.094759	1.628212	37860
10:38	1.7624	4.985545	1.606543	38280
10:44	1.8026	4.892724	1.587749	38640
11:35	2.1014	4.202805	1.435752	41700
11:50	2.1869	4.005389	1.387641	42600
12:13	2.3004	3.743321	1.319973	43980
12:18	2.325	3.68652	1.304683	44280
12:23	2.3477	3.634107	1.290363	44580
12:33	2.3937	3.527894	1.260701	45180
12:43	2.4395	3.422144	1.230267	45780
12:54	2.4849	3.317317	1.199156	46440
13:07	2.5373	3.196327	1.162002	47220
13:12	2.5575	3.149686	1.147303	47520
13:28	2.6203	3.004683	1.100172	48480


Well 1 Slug Test
LN(Y)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
35100
37100
39100
41100
43100
45100
47100
49100
Time, seconds
y = -0.0000511x + 3.5718519
R2 = 0.9956680
Series1
Linear (Series1)

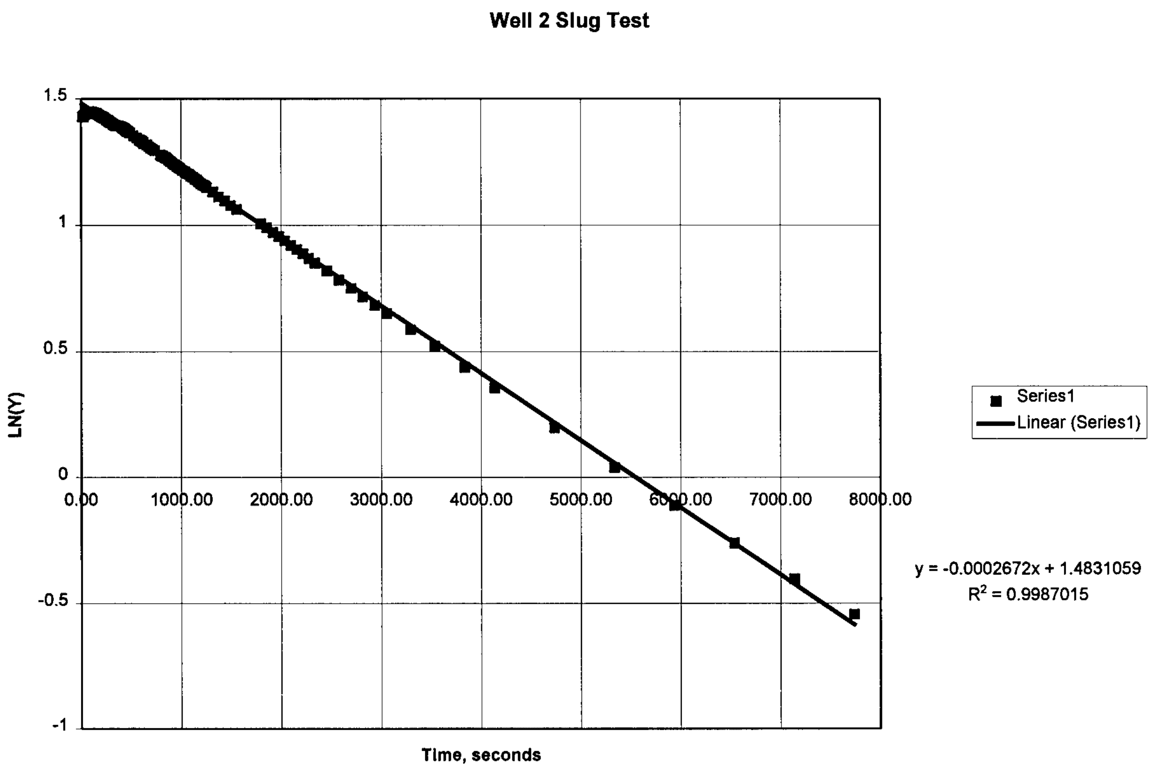
Well Number =	2			
Transducer Depth =	13	feet		
Casing Height =	814.1	feet		
Initial Water Depth =	5.79	feet	*from top of casing	
Water Depth after Slugging =		10.65	feet	*from top of casing
				*95.7 % recovery of well

Time, seconds	Pressure, psi	Y, feet	Ln(Y)	
0.00	0.201	4.86	1.581038	Initial Readings
5.00	1.092	5.152711	1.639523	
10.00	1.513	4.180637	1.430464	
15.00	1.516	4.17371	1.428805	
20.00	1.514	4.178328	1.429911	
25.00	1.51	4.187564	1.432119	
30.00	1.506	4.196799	1.434322	
35.00	1.501	4.208344	1.437069	
40.00	1.495	4.222198	1.440356	
45.00	1.492	4.229125	1.441995	
50.00	1.488	4.238361	1.444177	
55.00	1.484	4.247597	1.446353	
60.00	1.481	4.254524	1.447983	
65.00	1.48	4.256832	1.448525	
70.00	1.479	4.259141	1.449068	
75.00	1.478	4.26145	1.44961	
80.00	1.478	4.26145	1.44961	
85.00	1.477	4.263759	1.450151	
90.00	1.476	4.266068	1.450693	
95.00	1.478	4.26145	1.44961	
100.00	1.479	4.259141	1.449068	
105.00	1.48	4.256832	1.448525	
110.00	1.481	4.254524	1.447983	
115.00	1.483	4.249906	1.446897	
120.00	1.483	4.249906	1.446897	
125.00	1.484	4.247597	1.446353	
130.00	1.485	4.245288	1.44581	
135.00	1.487	4.24067	1.444721	
140.00	1.488	4.238361	1.444177	
145.00	1.489	4.236052	1.443632	
150.00	1.491	4.231434	1.442541	
155.00	1.492	4.229125	1.441995	
160.00	1.495	4.222198	1.440356	
165.00	1.498	4.215271	1.438714	
170.00	1.499	4.212962	1.438166	
175.00	1.501	4.208344	1.437069	

180.00	1.505	4.199108	1.434872
185.00	1.507	4.19449	1.433772
190.00	1.508	4.192181	1.433221
195.00	1.508	4.192181	1.433221
200.00	1.512	4.182946	1.431016
205.00	1.515	4.176019	1.429358
210.00	1.516	4.17371	1.428805
215.00	1.518	4.169092	1.427698
220.00	1.52	4.164474	1.42659
225.00	1.521	4.162165	1.426035
230.00	1.524	4.155238	1.42437
235.00	1.525	4.152929	1.423814
240.00	1.528	4.146002	1.422145
245.00	1.531	4.139075	1.420472
250.00	1.534	4.132148	1.418797
255.00	1.536	4.12753	1.417679
260.00	1.539	4.120603	1.416
265.00	1.54	4.118295	1.415439
270.00	1.544	4.109059	1.413194
275.00	1.546	4.104441	1.412069
280.00	1.549	4.097514	1.41038
285.00	1.551	4.092896	1.409253
290.00	1.553	4.088278	1.408124
295.00	1.555	4.08366	1.406994
300.00	1.558	4.076733	1.405296
305.00	1.56	4.072115	1.404163
310.00	1.562	4.067497	1.403028
315.00	1.564	4.062879	1.401892
320.00	1.566	4.058261	1.400755
325.00	1.569	4.051335	1.399046
330.00	1.571	4.046717	1.397906
335.00	1.573	4.042099	1.396764
350.00	1.576	4.035172	1.395049
365.00	1.579	4.028245	1.393331
380.00	1.58	4.025936	1.392757
400.00	1.583	4.019009	1.391035
405.00	1.586	4.012082	1.38931
410.00	1.588	4.007464	1.388159
415.00	1.59	4.002846	1.387006
420.00	1.593	3.995919	1.385274
425.00	1.596	3.988992	1.383539
430.00	1.598	3.984374	1.38238
435.00	1.601	3.977448	1.38064
440.00	1.604	3.970521	1.378897
445.00	1.606	3.965903	1.377734
450.00	1.609	3.958976	1.375985

455.00	1.611	3.954358	1.374818
460.00	1.614	3.947431	1.373065
465.00	1.616	3.942813	1.371894
470.00	1.618	3.938195	1.370723
475.00	1.622	3.928959	1.368375
480.00	1.625	3.922032	1.36661
485.00	1.626	3.919723	1.366021
525.00	1.645	3.875853	1.354766
555.00	1.659	3.843528	1.346391
580.00	1.671	3.81582	1.339156
585.00	1.674	3.808893	1.337339
590.00	1.675	3.806584	1.336732
595.00	1.677	3.801966	1.335518
600.00	1.68	3.795039	1.333695
605.00	1.68	3.795039	1.333695
610.00	1.685	3.783494	1.330648
615.00	1.687	3.778877	1.329427
620.00	1.69	3.77195	1.327592
625.00	1.693	3.765023	1.325754
655.00	1.705	3.737315	1.318367
675.00	1.715	3.714225	1.31217
695.00	1.725	3.691136	1.305934
715.00	1.734	3.670355	1.300288
735.00	1.742	3.651883	1.295243
795.00	1.768	3.59185	1.278667
815.00	1.775	3.575688	1.274157
835.00	1.784	3.554907	1.268329
855.00	1.79	3.541053	1.264424
875.00	1.8	3.517963	1.257882
895.00	1.809	3.497183	1.251958
915.00	1.819	3.474093	1.245333
935.00	1.827	3.455621	1.240002
955.00	1.837	3.432532	1.233298
975.00	1.844	3.416369	1.228578
995.00	1.853	3.395588	1.222477
1015.00	1.862	3.374807	1.216338
1035.00	1.868	3.360954	1.212225
1055.00	1.878	3.337864	1.205331
1075.00	1.883	3.326319	1.201866
1095.00	1.892	3.305538	1.195599
1115.00	1.9	3.287067	1.189996
1135.00	1.909	3.266286	1.183654
1155.00	1.916	3.250123	1.178693
1175.00	1.926	3.227034	1.171563
1195.00	1.935	3.206253	1.165103
1215.00	1.943	3.187781	1.159325

1235.00	1.949	3.173927	1.15497
1255.00	1.957	3.155456	1.149133
1315.00	1.98	3.102349	1.13216
1375.00	2.006	3.042316	1.112619
1435.00	2.028	2.991519	1.095781
1495.00	2.051	2.938413	1.07787
1555.00	2.071	2.892234	1.062029
1795.00	2.14	2.732915	1.005369
1855.00	2.158	2.691354	0.990044
1915.00	2.179	2.642865	0.971864
1975.00	2.198	2.598995	0.955125
2035.00	2.216	2.557434	0.939004
2095.00	2.235	2.513563	0.921701
2155.00	2.254	2.469693	0.904094
2215.00	2.272	2.428131	0.887122
2275.00	2.29	2.38657	0.869857
2335.00	2.308	2.345009	0.852289
2455.00	2.34	2.271122	0.820274
2575.00	2.375	2.190308	0.784042
2695.00	2.406	2.11873	0.750817
2815.00	2.436	2.049461	0.717577
2935.00	2.466	1.980192	0.683194
3055.00	2.493	1.91785	0.651205
3295.00	2.546	1.795475	0.585269
3535.00	2.595	1.682335	0.520183
3835.00	2.653	1.548415	0.437232
4135.00	2.705	1.428349	0.356519
4735.00	2.796	1.218233	0.197402
5335.00	2.873	1.040443	0.039646
5935.00	2.936	0.894978	-0.11096
6535.00	2.99	0.770294	-0.26098
7135.00	3.034	0.668699	-0.40242
7735.00	3.072	0.580959	-0.54308

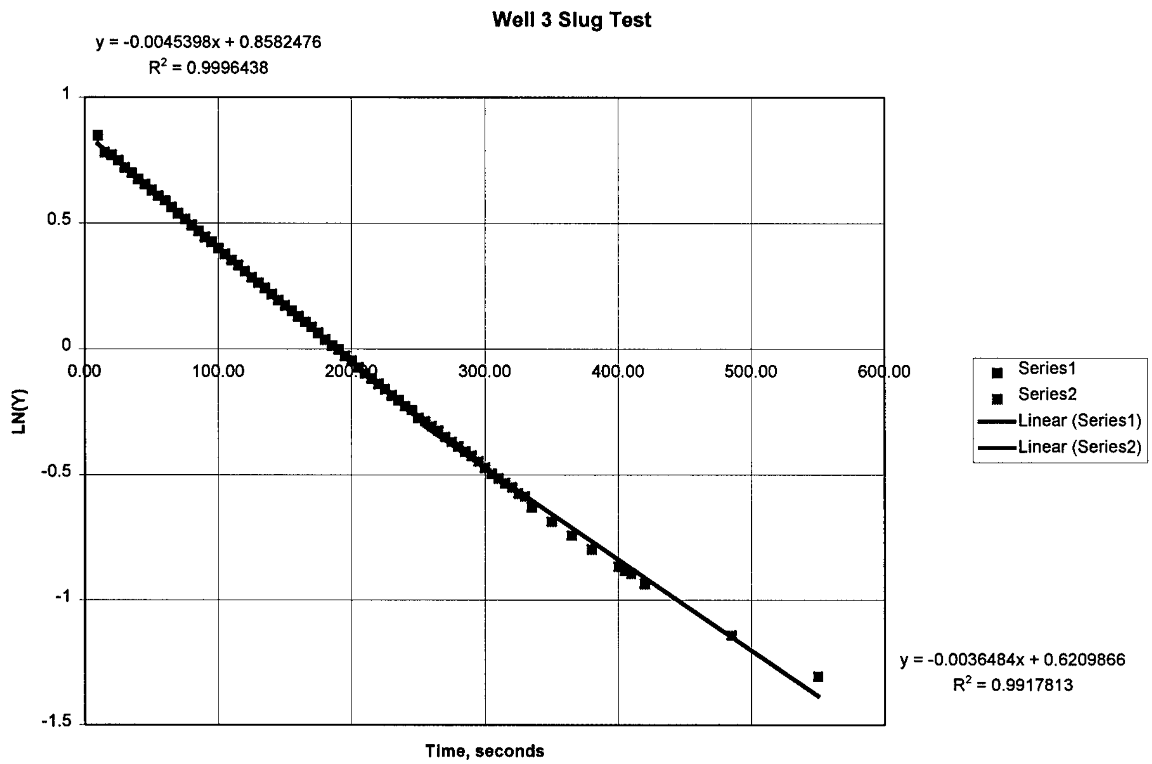


Well 2 Slug Test
1.5
1
0.5
0
-0.5
-1
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
7000.00
8000.00
LN(Y)
Time, seconds
Series1
Linear (Series1)
y = -0.0002672x + 1.4831059
R2 = 0.9987015

Well Number =	3		
Transducer Depth =	12	feet	
Casing Height =	818.1	feet	
Initial Water Depth =	6.47	feet	*from top of casing
Water Depth after Slugging =	8.82	feet	*from top of casing
			*97.44% recovery

Time, seconds	Pressure, psi	Y, feet	Ln(Y)	
0.00	0.1933	2.35	0.854415	Initial Readings
5.00	2.048	1.247561	0.22119	
10.00	1.577	2.335084	0.848048	
15.00	1.643	2.182692	0.780559	
20.00	1.653	2.159602	0.769924	
25.00	1.672	2.115732	0.749401	
30.00	1.698	2.055699	0.720616	
35.00	1.717	2.011829	0.699044	
40.00	1.738	1.96334	0.674647	
45.00	1.756	1.921779	0.653251	
50.00	1.775	1.877908	0.630159	
55.00	1.793	1.836347	0.607778	
60.00	1.808	1.801713	0.588738	
65.00	1.827	1.757842	0.564087	
70.00	1.846	1.713972	0.538813	
75.00	1.862	1.677028	0.517023	
80.00	1.879	1.637776	0.493339	
85.00	1.896	1.598524	0.46908	
90.00	1.912	1.56158	0.445698	
95.00	1.925	1.531564	0.426289	
100.00	1.941	1.49462	0.401872	
105.00	1.956	1.459986	0.378427	
110.00	1.971	1.425351	0.354418	
115.00	1.983	1.397644	0.334788	
120.00	1.998	1.363009	0.309695	
125.00	2.012	1.330684	0.285693	
130.00	2.024	1.302976	0.264651	
135.00	2.036	1.275268	0.243157	
140.00	2.049	1.245252	0.219338	
145.00	2.062	1.215235	0.194938	
150.00	2.073	1.189837	0.173816	
155.00	2.084	1.164438	0.152239	
160.00	2.095	1.139039	0.130185	
165.00	2.106	1.113641	0.107635	
170.00	2.116	1.090551	0.086683	
175.00	2.127	1.065152	0.063118	

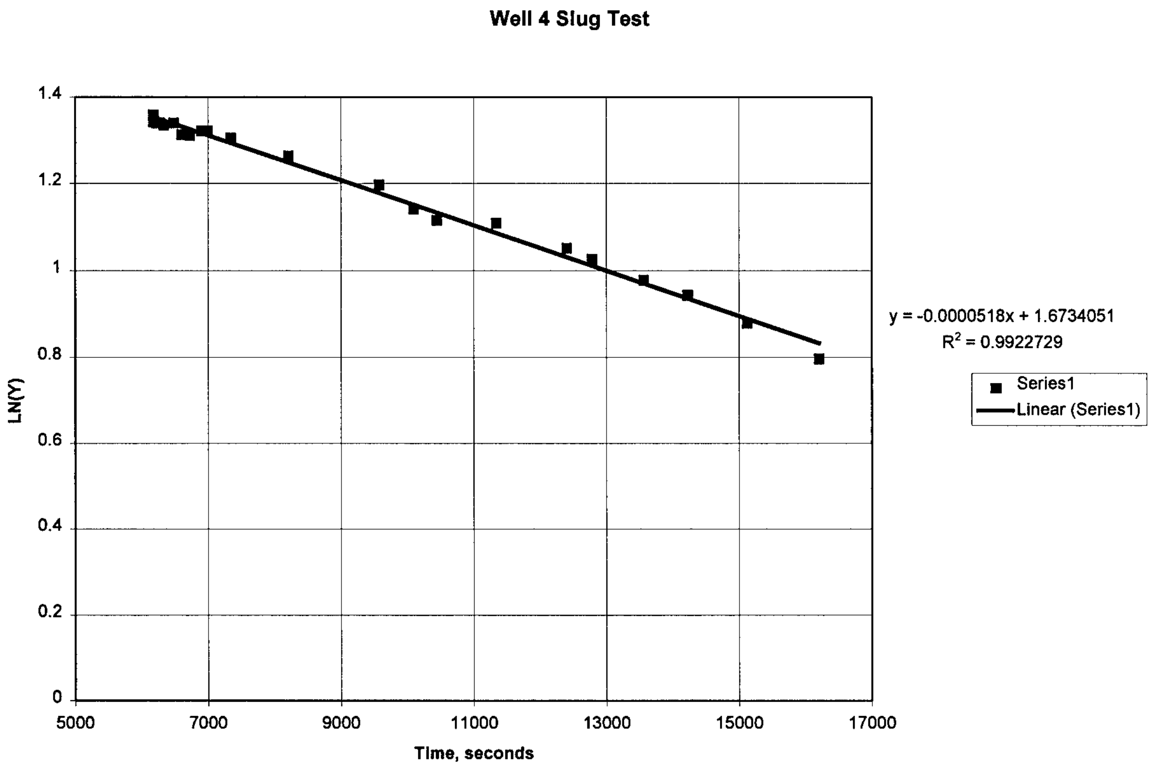
180.00	2.139	1.037445	0.036761
185.00	2.149	1.014355	0.014253
190.00	2.156	0.998192	-0.00181
195.00	2.167	0.972794	-0.02758
200.00	2.175	0.954322	-0.04675
205.00	2.186	0.928923	-0.07373
210.00	2.195	0.908143	-0.09635
215.00	2.203	0.889671	-0.1169
220.00	2.211	0.871199	-0.13788
225.00	2.219	0.852728	-0.15932
230.00	2.228	0.831947	-0.18399
235.00	2.235	0.815784	-0.20361
240.00	2.243	0.797312	-0.22651
245.00	2.249	0.783459	-0.24404
250.00	2.259	0.760369	-0.27395
255.00	2.263	0.751133	-0.28617
260.00	2.27	0.73497	-0.30793
265.00	2.275	0.723425	-0.32376
270.00	2.283	0.704954	-0.34962
275.00	2.289	0.6911	-0.36947
280.00	2.294	0.679555	-0.38632
285.00	2.3	0.665701	-0.40691
290.00	2.305	0.654156	-0.42441
295.00	2.311	0.640303	-0.44581
300.00	2.318	0.62414	-0.47138
305.00	2.324	0.610286	-0.49383
310.00	2.329	0.598741	-0.51293
315.00	2.334	0.587196	-0.5324
320.00	2.338	0.577961	-0.54825
325.00	2.344	0.564107	-0.57251
330.00	2.347	0.55718	-0.58487
335.00	2.357	0.53409	-0.62719
350.00	2.37	0.504074	-0.68503
365.00	2.382	0.476366	-0.74157
380.00	2.393	0.450967	-0.79636
400.00	2.406	0.420951	-0.86524
405.00	2.409	0.414024	-0.88183
410.00	2.411	0.409406	-0.89305
420.00	2.418	0.393243	-0.93333
485.00	2.45	0.319356	-1.14145
550.00	2.471	0.270868	-1.30612



Well 3 Slug Test
y = -0.0045398x + 0.8582476
R2 = 0.9996438
1
0.5
0
-0.5
-1
-1.5
0.00
100.00
200.00
300.00
400.00
500.00
600.00
LN(Y)
Time, seconds
Series1
Series2
Linear (Series1)
Linear (Series2)
y = -0.0036484x + 0.6209866
R2 = 0.9917813

Well Number =	4			
Transducer Depth =	NA	feet	*Done by hand (no transducer)	
Casing Height =	832	feet	*88.28 % recovered	
Initial Water Depth =	16.73	feet	*from top of casing	
Water Depth after Slugging =		20.62	feet	*from top of casing

Time, minutes	Water Level, ft	Y, feet	Ln(Y)	Time, sec	
1:42:52	20.62	3.89	1.358409	6172	Initial Readings
1:42:52	20.56	3.83	1.342865	6172	
1:43:45	20.55	3.82	1.34025	6225	
1:44:30	20.55	3.82	1.34025	6270	
1:45:30	20.53	3.8	1.335001	6330	
1:48:00	20.55	3.82	1.34025	6480	
1:50:00	20.45	3.72	1.313724	6600	
1:52:00	20.44	3.71	1.311032	6720	
1:55:00	20.48	3.75	1.321756	6900	
1:56:30	20.48	3.75	1.321756	6990	
2:02:18	20.42	3.69	1.305626	7338	
2:16:44	20.27	3.54	1.264127	8204	
2:39:30	20.04	3.31	1.196948	9570	
2:48:10	19.86	3.13	1.141033	10090	
2:54:00	19.78	3.05	1.115142	10440	
3:09:00	19.76	3.03	1.108563	11340	
3:26:40	19.59	2.86	1.050822	12400	
3:33:00	19.52	2.79	1.026042	12780	
3:46:00	19.39	2.66	0.978326	13560	
3:57:00	19.3	2.57	0.943906	14220	
4:12:00	19.14	2.41	0.879627	15120	
4:30:00	18.95	2.22	0.797507	16200	

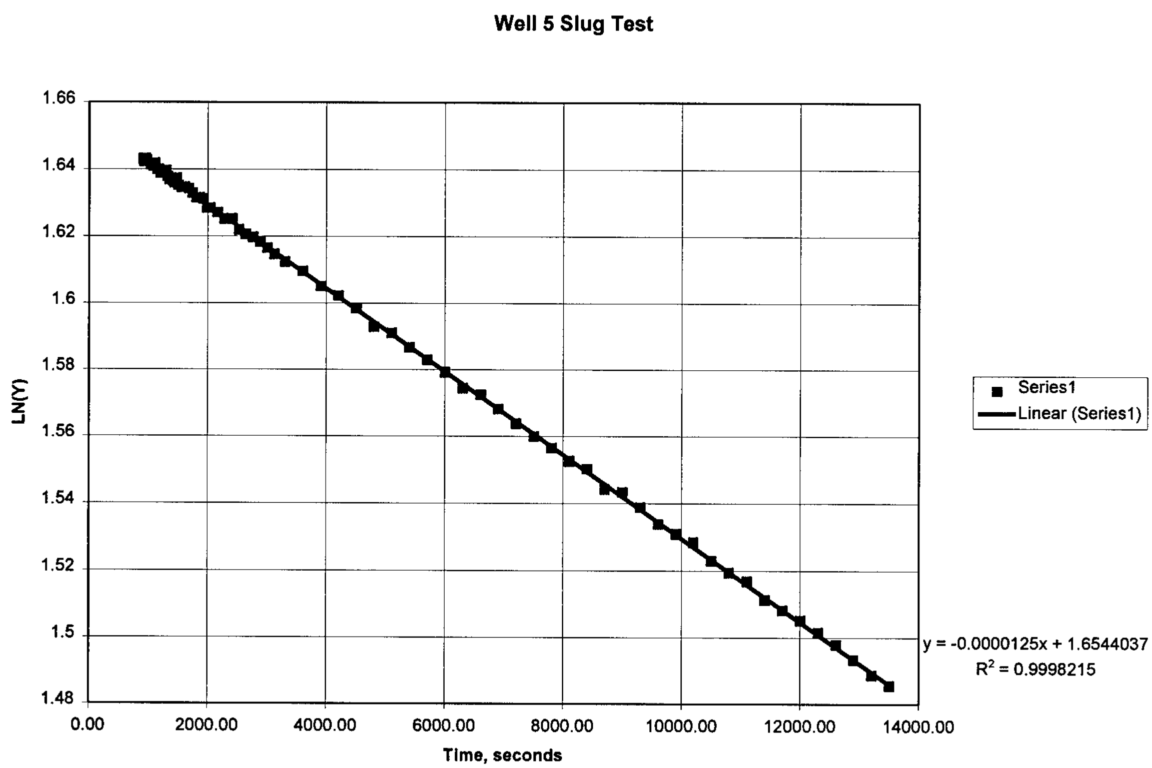


Well 4 Slug Test
1.4
1.2
1
0.8
0.6
0.4
0.2
0
LN(Y)
5000
7000
9000
11000
13000
15000
17000
Time, seconds
y = -0.0000518x + 1.6734051
R2 = 0.9922729
Series1
Linear (Series1)

Well Number =	5		
Transducer Depth =	13	feet	
Casing Height =	821.6	feet	*51.1% recovered
Initial Water Depth =	4.79	feet	*from top of casing
Water Depth after Slugging =	10.15	feet	*from top of casing

Time, seconds	Pressure, psi	Y, feet	Ln(Y)	
0.00	0.1593	5.36	1.678964	Initial Readings
915.00	1.475	5.172093	1.643278	
920.00	1.476	5.169784	1.642831	
925.00	1.477	5.167476	1.642384	
930.00	1.477	5.167476	1.642384	
935.00	1.476	5.169784	1.642831	
940.00	1.476	5.169784	1.642831	
945.00	1.476	5.169784	1.642831	
950.00	1.475	5.172093	1.643278	
955.00	1.476	5.169784	1.642831	
960.00	1.476	5.169784	1.642831	
1035.00	1.479	5.162858	1.64149	
1080.00	1.48	5.160549	1.641043	
1110.00	1.478	5.165167	1.641937	
1140.00	1.482	5.155931	1.640148	
1170.00	1.482	5.155931	1.640148	
1200.00	1.485	5.149004	1.638803	
1230.00	1.485	5.149004	1.638803	
1260.00	1.485	5.149004	1.638803	
1290.00	1.483	5.153622	1.6397	
1320.00	1.487	5.144386	1.637906	
1350.00	1.489	5.139768	1.637008	
1380.00	1.488	5.142077	1.637457	
1410.00	1.49	5.137459	1.636559	
1440.00	1.491	5.13515	1.636109	
1470.00	1.488	5.142077	1.637457	
1500.00	1.493	5.130532	1.635209	
1560.00	1.494	5.128223	1.634759	
1620.00	1.494	5.128223	1.634759	
1680.00	1.495	5.125914	1.634309	
1740.00	1.498	5.118987	1.632957	
1800.00	1.501	5.11206	1.631603	
1860.00	1.501	5.11206	1.631603	
1920.00	1.502	5.109751	1.631151	
1980.00	1.508	5.095898	1.628436	
2040.00	1.508	5.095898	1.628436	

2160.00	1.511	5.088971	1.627076
2280.00	1.515	5.079735	1.625259
2400.00	1.515	5.079735	1.625259
2520.00	1.522	5.063572	1.622072
2640.00	1.525	5.056645	1.620703
2760.00	1.527	5.052027	1.61979
2880.00	1.53	5.0451	1.618418
3000.00	1.534	5.035864	1.616585
3120.00	1.538	5.026629	1.614749
3300.00	1.543	5.015084	1.61245
3600.00	1.549	5.00123	1.609684
3900.00	1.559	4.97814	1.605056
4200.00	1.565	4.964286	1.60227
4500.00	1.573	4.945815	1.598542
4800.00	1.585	4.918107	1.592924
5100.00	1.589	4.908871	1.591044
5400.00	1.598	4.888091	1.586802
5700.00	1.606	4.869619	1.583016
6000.00	1.614	4.851147	1.579215
6300.00	1.624	4.828057	1.574444
6600.00	1.628	4.818822	1.572529
6900.00	1.637	4.798041	1.568208
7200.00	1.646	4.77726	1.563867
7500.00	1.654	4.758789	1.559993
7800.00	1.661	4.742626	1.556591
8100.00	1.669	4.724154	1.552689
8400.00	1.674	4.712609	1.550242
8700.00	1.686	4.684902	1.544345
9000.00	1.688	4.680284	1.543359
9300.00	1.697	4.659503	1.538909
9600.00	1.707	4.636413	1.533941
9900.00	1.713	4.62256	1.530949
10200.00	1.718	4.611015	1.528448
10500.00	1.729	4.585616	1.522924
10800.00	1.736	4.569453	1.519394
11100.00	1.741	4.557908	1.516864
11400.00	1.752	4.53251	1.511276
11700.00	1.758	4.518656	1.508215
12000.00	1.764	4.504802	1.505144
12300.00	1.771	4.488639	1.50155
12600.00	1.778	4.472477	1.497942
12900.00	1.787	4.451696	1.493285
13200.00	1.796	4.430915	1.488606
13500.00	1.802	4.417062	1.485475



Well 5 Slug Test
1.66
1.64
1.62
1.6
1.58
1.56
1.54
1.52
1.5
1.48
LN(Y)
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
14000.00
Time, seconds
Series1
Linear (Series1)
y = -0.0000125x + 1.6544037
R^2 = 0.9998215

APPENDIX D: Seepage Data and Calculations

Initial Data

North Lagoon:

Bottom Lagoon Elevation = 797'

Top elevation = 829'

Water level = 829' - 6.3' = 822.7' water depth = 25.7'

Volume of water = (LW x LL x LD) - (S x LD^2) x (LW + LL) + $\left(\frac{4 \times S^2 LD^3}{3}\right)$

South Lagoon:

Top elev = 828.6'

Water elev = 828.6' - 6.3' = 822.3'

water depth = 25.3'

Iowa Seepage allowed = 0.0015875 m/d → 1/16"/day

North Lagoon = 86.9 m x 43 m x 0.0015875 m/d

= 2.52 m^3/day ≈ 665 gal/day
acceptable

South Lagoon = 24.7 m x 39.95 m x 0.0015875 m/d

= 1.566 m^3/day ≈ 414 gal/day
acceptable

Seepage Calculations

Lagoon Seepage (half lagoon) $K_s = (MW\,4) = 2.475 \times 10^{-6}$ cm/sec

2-D (ignores ends - does parallel sides and bottom)

$$Q_L = \frac{K_s}{2W}\left(H_p^2 - H_s^2\right) = \frac{m^3}{m \cdot hr}$$

$$= \frac{\left(2.475 \times 10^{-6}\ \text{cm/sec}\right)\left(\frac{1\,m}{100\,cm}\right)}{2(202\,m)}\left((250.64\,m)^2 - (240.792\,m)^2\right)$$

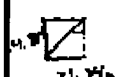
at Lagoon midpoint of system

$$Q_L = 2.965 \times 10^{-7}\ m^3/m \cdot hr\ (\times 2) = 5.93 \times 10^{-7}\ m^3/m \cdot hr$$

Length = 160 m

North → $160\,m \times 5.93 \times 10^{-7}\ m^3/m \cdot hr$ = $9.487 \times 10^{-5}\ m^3/hr$ ≈ 0.60 gal/day

South → $100\,m \times 5.93 \times 10^{-7}\ m^3/m \cdot hr$ = $5.93 \times 10^{-5}\ m^3/hr$ ≈ 0.376 gal/day



$\tan \alpha = \frac{21.34}{24.384}$

$\alpha = 41.19°$

3-D Seepage: (North Lagoon)

$$Q = \frac{k_s L_e}{2W_e}\left(H_p^2 - H_s^2\right)$$

$$R = L_p + \frac{L}{2}$$ spacing to the drain

$$= 24.384\,m + \frac{5\,m}{2} = 26.884\,m$$

$$= \frac{\left(2.475 \times 10^{-6}\ \text{cm/sec}\right)\left(\frac{1\,m}{100\,cm}\right)L_e}{2(W_e)}\left(4839.62\,m^2\right)$$

$$W_e = W + W_p - R\cos\alpha$$

$$= 202\,m + 21.34\,m - 26.884\,m\cos(41.19°)$$

$$W_e = 203.109\,m$$

$$L_e = \frac{L + L_p}{1 + \left[\frac{2(L+L_p)}{W_e \pi}\right] \ln\left(R/L_p\right)}$$

$$= \frac{5m + 24.384m}{1 + \left[\frac{2(29.384m)}{203.169m\,\pi}\right] \ln\left(\frac{26.884}{24.384}\right)}$$

$$L_e = 29.122\,m$$

$$Q = \frac{\left(2.475 \times 10^{-6}\,cm/sec\right)\left(\frac{1m}{100cm}\right)\left(29.122m\right)}{2(203.169m)}\left(4839.62m^2\right)$$

$$Q = 8.5872 \times 10^{-6}\,m^3/hr \quad (\times 4 \text{ since } 1/4 \text{ panel size})$$

$$\underline{Q = 3.43 \times 10^{-5}\,m^3/hr} \rightarrow 0.218\,gal/day$$

South Lagoon:

$$W_e = 202m + 22.86m - 17.74m\cos(56.31°) = 215.02m$$

$$R = 15.24m + \frac{5m}{2} = 17.74m$$

$$\alpha = \mathrm{ATAN}\left(\frac{22.86}{15.24}\right) = 56.31°$$

$$L_e = \frac{5m + 15.24}{1 + \left[\frac{2(20.24)}{215.02\,\pi}\right]\ln\left(\frac{17.74}{15.24}\right)} = 20.0574m$$

$$Q_{1/4} = \frac{\left(2.475 \times 10^{-6}\,cm/sec\right)\left(\frac{1m}{100cm}\right)\left(20.0574m\right)}{2(215.02m)}\left(4839.62m^2\right)$$

$$\boxed{Q = 2.23 \times 10^{-5}\,m^3/hr \rightarrow 0.142\,gal/d}$$

Permissible Seepage (according to Iowa Law):

Kirkwood Lagoon 2-D Seepage Calculations

Input Variables:

K_s =	4.38E-03	cm/sec
H_p =	250.64	m
H_s =	240.792	m
W =	202	m
Length =	100	m
Lagoon =	South	

Solution

:

Actual Rates

Q_L = 0.00105 $m^3/m*hr$

Q_{actual} = 0.105 m^3/hr

	Actual Rates		Iowa Standards*		Difference =
Q_{actual} =	2.520001	m^3/day	2.52	m^3/day	9.45E-07

*based on 1/16" / day for liquid area in lagoons

Q_{actual} = 665.6 gal/day

Actual Seepage from North Lagoon:

Kirkwood Lagoon 2-D Seepage Calculations

Input Variables:

K_s =	2.50E-06	cm/sec
H_p =	250.64	m
H_s =	240.792	m
W =	202	m
Length =	100	m
Lagoon =	North	

Solution

:

Actual Rates

Q_L = 5.99E-07 m^3/m*hr

Q_{actual} = 5.99E-05 m^3/hr

	Actual Rates		Iowa Standards*		Difference =
Q_{actual} =	0.001438	m^3/day	2.52	m^3/day	-2.51856

*based on 1/16" / day for liquid area in lagoons

Q_{actual} = 0.4 gal/day

Actual Seepage from South Lagoon:

Kirkwood Lagoon 2-D Seepage Calculations

Input Variables:

K_s =	5.97E-07	cm/sec
H_p =	250.64	m
H_s =	240.792	m
W =	202	m
Length =	100	m
Lagoon =	South	

Solution

:

Actual Rates

Q_L = 1.43E-07 m^3/m*hr

Q_{actual} = 1.43E-05 m^3/hr

			Iowa Standards*		Difference =
Q_{actual} =	0.000343	m^3/day	2.52	m^3/day	-2.51966

*based on 1/16" / day for liquid area in lagoons

Q_{actual} = 0.1 gal/day

APPENDIX E: Surface Water Quality Calculations

Flow Calculations

Stream Analysis

Flow Calculations:

$R = \frac{D}{4} = \frac{4\text{inch}}{4} = 1\text{inch} = 8.333\times10^{-2}\text{ft}$

$C = 2\pi r = \pi D = 1.0472\text{ ft}$

$\text{Area} = \pi r^2 = \frac{\pi D^2}{4} = \frac{\pi (4\text{inch})^2}{4}$

$= 12.566\text{ in}^2$

$A = 0.087266\text{ ft}^2$

$Q = VA$

Mannings Eqn

$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$

Flow $\rightarrow Q = \frac{1.49}{0.012} (0.0833\text{ ft})^{2/3} (0.087266\text{ ft}^2) \left(\frac{20\text{ft}}{500}\right)^{1/2} =$

KTown Drainage Guide

$Q = 0.4135\text{ cfs} = 1.2\times10^{-2}\text{ m}^3/\text{sec}$

Stream Velocity $\rightarrow$ 1.654 fps (Area = 3" x 1')

= 0.504 m/sec

H = mean depth = 3" x 1'

Froude Number = $\frac{\text{Velocity}}{\sqrt{gH}} = \frac{1654\text{ ft/sec}}{\sqrt{32.2 \cdot \frac{3"}{12"}}} = 0.583$

< 1

subcritical flow

River Dispersion Coefficient:

$E_x = 3.4\times10^{-5} \frac{u^2 B^2}{H u^*} = \frac{(1.654\text{ fps})^2 (1')^2}{(3/12')(0.567\text{ fps})} =$

$u^* = \sqrt{gHS} = \sqrt{32.2 \cdot \frac{3"}{12"} \cdot \frac{20'}{500'}} = 0.567\text{ fps}$

$E_x = 6.56\times10^{-4}\text{ mi}^2/\text{day}$

Surface Water Quality Modeling

Assume Recharge is point source

Ammonia Analysis (K_1 is Assumed ≥ K_1 for NO_3)

$S_0 = 0.5\ mg/L$

$S = 0.5\ mg/L\ \exp\left(\frac{-kx}{u}\right)$ $\qquad K_1 = -0.00067$

$= 0.5\ mg/L\ \exp\left(\frac{-(-0.00067)(152.4\ m)}{0.504\ m/s}\right)$

$= 0.61\ mg/L$ based on aquifer organisms → Not so in Streams so will be less

Chloride levels will remain constant.

<u>Steady Input of Nitrate:</u> 10 mg/L

X = 1 mile downstream

$u = 27.06$ mi/d
x = 1 mile $\quad t = 365$ d
τ = 30 days or $t = 3$ d

$$S(x,t) = \frac{S_0}{2} \exp\left(-\frac{Kx}{u}\right)\left[\operatorname{erf}\left(\frac{x - u(t-\tau)(1+n)}{\sqrt{4E_x(t-\tau)}}\right) - \operatorname{erf}\left(\frac{x - ut(1+n)}{\sqrt{4E_x t}}\right)\right]$$

$-\operatorname{erf}(\infty) = -1 \qquad + \operatorname{erf}(\infty) = 1$

Assume $k = 0.1$/hr

$$n = \frac{kE_x}{u^2} = \frac{(0.\ /d)(6.56 \times 10^{-4}\ mi^2/d)}{\left[\left(\frac{86400\,s}{1\,d}\right)(0.504\ m/sec)\left(\frac{1\,mi}{1609.344\,m}\right)\right]^2} = 1.209 \times 10^{-9}$$

$S(x,t) = \emptyset$ mg/L

APPENDIX F: Ammonia-nitrogen Calculations for Kirkwood Stream Samples

Ammonia-N Data

Kirkwood Lagoons Project—Ammonia-N Samples
Microdiffusion Method

Sample Name	Sample Size, mL	Titration Amount, μL	Average, mL
South Lagoon 1	0.1	162.0	
South Lagoon 2	0.1	172.0	167.0
North Lagoon 1	0.1	248.0	
North Lagoon 2	0.1	250.0	249.0
South Creek 1	1.0	3.0	
South Creek 2	1.0	5.0	4.0
North Creek 1	1.0	5.0	
North Creek 2	1.0	3.0	4.0
North Creek Well 1	1.0	5.0	
North Creek Well 2	1.0	3.0	4.0
North Creek + 10 μg spike NH_3-N (1)	1.0	42.0	
North Creek + 10 μg spike NH_3-N (2)	1.0	42.0	42.0
10 μg spike NH_3-N	1.0	50.0	
Blank 1	1.0	1.0	
Blank 2	1.0	2.0	1.5

Ammonia-N Concentrations

Solution:

Blank Percent Recovery:

Percent Recovery of Spike =	97	%

Sample Percent Recovery:

Percent Recovery of Spike =	73	%

South Lagoon:

PPM NH_3-N =	331.0

North Lagoon:

PPM NH_3-N =	495.0

South Creek

PPM NH_3-N =	0.5

North Creek:

PPM NH_3-N =	0.5

North Creek Subsurface:

PPM NH_3-N =	0.5

North Creek + Spike:

PPM NH_3-N =	8.1

APPENDIX G: Chloride Determination in Kirkwood Lagoons and Stream Samples

Chloride Data

Kirkwood Lagoons Project--Chloride Samples

Turbidimetric Method

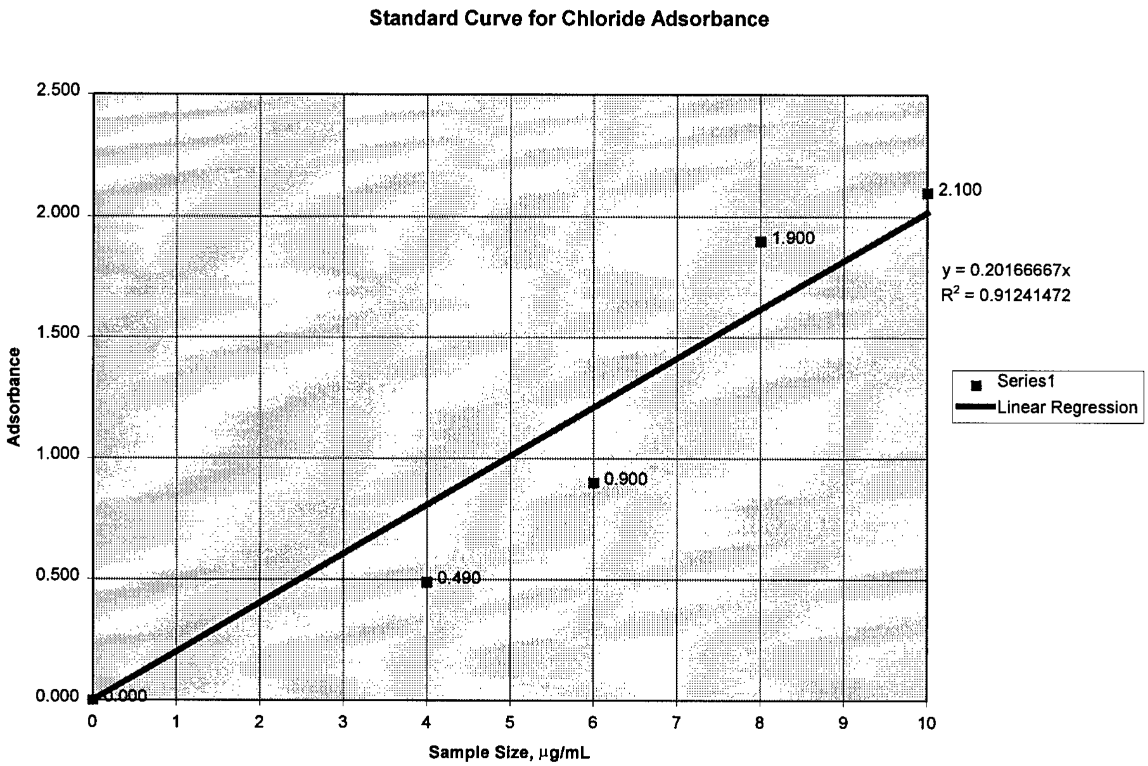
(May 1997)

Spike Amount = 4.00 μg/mL

Sample Name	Sample Size, mL	Dilution Water Size, mL	Absorbance
South Lagoon 1	0.1	19.0	0.210
South Lagoon 2	0.1	19.0	0.200
South Lagoon Blank	0.1	19.0	0.205
North Lagoon Blank	0.1	19.0	0.390
North Lagoon 1	0.1	19.0	0.420
North Lagoon 2	0.1	19.0	0.430
South Creek 1	1.0	19.0	0.160
South Creek 2	1.0	19.0	0.200
South Creek + Spike	1.0	19.0	0.770
North Creek 1	1.0	19.0	0.030
North Creek 2	1.0	19.0	0.045
North Creek + Spike	1.0	19.0	0.530
North Creek Well 1	1.0	19.0	0.140
North Creek Well 2	1.0	19.0	0.160
North Creek Well + spike	1.0	19.0	0.950

Sample Name	Concentration of Standard, μg/mL	Absorbance
Blank + Spike	4	0.460
Blank 1	0	0.000
Standard 4	4	0.490
Standard 6	6	0.900
Standard 8	8	1.900
Standard 10	10	2.100

Chloride Standard Curve



Chloride Concentrations

Solution:

Slope of Regression Line =	0.2016667	Chloride absorbance / μg/mL

Sample Name	Absorbance	Chloride Concentration, ppm (mg/L)	% Spike Recovery
South Lagoon 1	0.210	197.9	N/A
South Lagoon 2	0.200	188.4	N/A
South Lagoon Blank	0.205	193.1	N/A
North Lagoon Blank	0.390	367.4	N/A
North Lagoon 1	0.420	395.7	N/A
North Lagoon 2	0.430	405.1	N/A
South Creek 1	0.160	15.1	N/A
South Creek 2	0.200	18.8	N/A
South Creek + Spike	0.770	72.5	73.1%
North Creek 1	0.030	2.8	N/A
North Creek 2	0.045	4.2	N/A
North Creek + Spike	0.530	49.9	61.1%
North Creek Well 1	0.140	13.2	N/A
North Creek Well 2	0.160	15.1	N/A
North Creek Well + spike	0.950	89.5	99.2%
		Average % =	77.79%

Statistical Analysis

Sample Name	Absorbance	Chloride Concentration, ppm (mg/L)	% Spike Recovery
South Creek 1	0.160	15.1	N/A
South Creek 2	0.200	18.8	N/A
North Creek 1	0.030	2.8	N/A
North Creek 2	0.045	4.2	N/A
North Creek Well 1	0.140	13.2	N/A
North Creek Well 2	0.160	15.1	N/A

Chloride Statistical Analysis

All Data Points

	Chloride Concentration, ppm (mg/L)
Mean	11.54132041
Standard Error	2.647392874
Median	14.13222907
Mode	15.07437767
Standard Deviation	6.48476169
Sample Variance	42.05213418
Kurtosis	-1.590122597
Skewness	-0.626188831
Range	16.01652628
Minimum	2.826445814
Maximum	18.84297209
Sum	69.24792244
Count	6
Confidence Level(95.0%)	6.805328913

South Creek Analysis

	Chloride Concentration, ppm (mg/L)
Mean	16.95867488
Standard Error	1.884297209
Median	16.95867488
Mode	#N/A
Standard Deviation	2.664798669
Sample Variance	7.101151945
Kurtosis	#DIV/0!
Skewness	#DIV/0!
Range	3.768594418
Minimum	15.07437767
Maximum	18.84297209
Sum	33.91734977
Count	2
Confidence Level(95.0%)	23.94216355

North Creek Analysis

Column1	
Mean	3.533057267
Standard Error	0.706611453
Median	3.533057267
Mode	#N/A
Standard Deviation	0.999299501
Sample Variance	0.998599492
Kurtosis	#DIV/0!
Skewness	#DIV/0!
Range	1.413222907
Minimum	2.826445814
Maximum	4.239668721
Sum	7.066114535
Count	2
Confidence Level(95.0%)	8.978311332

North Creek Well Analysis

Column1	
Mean	14.13222907
Standard Error	0.942148605
Median	14.13222907
Mode	#N/A
Standard Deviation	1.332399334
Sample Variance	1.775287986
Kurtosis	#DIV/0!
Skewness	#DIV/0!
Range	1.884297209
Minimum	13.19008046
Maximum	15.07437767
Sum	28.26445814
Count	2
Confidence Level(95.0%)	11.97108178

APPENDIX H: Contaminant Transport and Biodegradation Data and Calculations

Contaminant Transport Data

MW Name	Mean Cl Concentrations of Wells
4	142.6736111
3	67.335
2	53.26111111

Chloride Tracer Test for Longitudinal Dispersion	
Mean	60.29805556
Standard Error	7.036944444
Median	60.29805556
Mode	#N/A
Standard Deviation	9.951742271
Sample Variance	99.03717423
Kurtosis	#DIV/0!
Skewness	#DIV/0!
Range	14.07388889
Minimum	53.26111111
Maximum	67.335
Sum	120.5961111
Count	2
Confidence Level(95.0%)	89.41247377

Water Table Gradient Statistics

Summary Statistics for Water Table Slope	
Mean	-0.041812228
Standard Error	0.0004702
Median	-0.03454715
Mode	-0.0292889
Standard Deviation	0.017237803
Sample Variance	0.000297142
Kurtosis	12.17561379
Skewness	-2.723524071
Range	0.1617095
Minimum	-0.188211
Maximum	-0.0265015
Sum	-56.1956342
Count	1344
Confidence Level(95.0%)	0.000922405

Contaminant Transport Calculations

Ground water Transport of Contaminants

MCL (mg/L)

$Cl^- = 250$

$NO_3^- - N = 10$

$SO_4^{2-} = 400-500$ or 250 mg/L secondary EPA

TOC background levels = 1 → 20 mg/L   Geol 554 notes

Porosity of silty materials/fine grained   0.10 → 0.3

K values of glacial till = $10^{-10} \rightarrow 10^{-4}$ cm/sec

Assume gradient = $\frac{dh}{dl} = 0.0418$

Acetic acids and propionic acids odorous compounds (highest conc) 475 notes

<u>Diffusion coefficients</u> (@ 25°C) D_{H_2O}

Ammonia = 1.64×10^{-5} cm²/sec
Acetic acid = 1.21×10^{-5} cm²/sec
Propionic acid = 1.06×10^{-5} cm²/sec

$D_{effective} = \tau \times D_{H_2O}$

apparent Tortuosity factor $\tau = \theta^P$ P varies based on soil K's   1.3 → 5.4 (high K, Low K)

θ Glacier till = $\frac{0.1 + 0.3}{2} = 0.2$

$\tau = (0.2)^{4.1} = 1.362 \times 10^{-3}$ for glacial till

Ammonia-$D_{effective}$ = $(1.362 \times 10^{-3})(1.64 \times 10^{-5}\ cm^2/sec) = 2.23 \times 10^{-8}\ cm^2/s$
Acetic Acid D_{eff} = $(1.362 \times 10^{-3})(1.21 \times 10^{-5}\ cm^2/sec) = 1.648 \times 10^{-8}\ cm^2/sec$

2

Propionic Acid = $(1.362 \times 10^{-3})(1.06 \times 10^{-5}\ cm^2/sec)$ =

$= 1.444 \times 10^{-8}\ cm^2/sec$

Check if diffusion is player in transport

Initial NH_3 concentration in North lagoon = 310 mg/L

* Assuming the soil has infinite thickness,

$$\frac{C(z,t)}{C_0} = ERFC\left[\frac{z}{(4Dt)^{1/2}}\right]$$

$t = 1$ yr = 31556296 sec

$z = 1$ meter below surface

$$= ERFC\left[\frac{1m}{\left((4)(2.23 \times 10^{-8}\ cm^2/sec)(31556296\ sec)\right)^{1/2}}\right]$$

$$= ERFC\left[\frac{1m}{1.67 \times 10^{-2}\ m}\right]$$

$$= ERFC\left[59.6\right]$$

$$\frac{C(z)}{C_0} \approx \emptyset$$

Diffusion is Not a major player in this situation

31

Advection Transport

hydraulic gradient = 0.0418 m/m

v_D = Darcy Velocity = $\frac{Q}{A} = -K\frac{dh}{dx}$ $\left(\frac{L^3}{L^2 \cdot t}\right)$

Darcy's Law

$$Q = -KA\frac{dh}{dx}$$

Average Linear Velocity

$$v_x = \frac{-K}{n_e} \cdot \frac{dh}{dl} \qquad v_x > v_D$$

Oxidized clay till $n_e = 0.1$ 1 day = 86400 sec

Kirkwood Advection:

* Assume highest K @ well # 3 → 2.0×10^{-4} cm/sec *(ave of 3a + 3b)

$$v_x = \frac{-2.0\times10^{-4}\,\text{cm/sec}}{0.1} \cdot \left(-0.04196\,\text{m/m}\right)$$

$$v_x = 0.0000836\ \text{cm/sec} \rightarrow \underline{\underline{0.0722\ \text{m/d}}}$$

or 7.2 cm/d

Time to reach stream = $t = \frac{d}{v_x} = \frac{202\,\text{m}}{0.0722\,\text{m/d}} = 2797$ days to reach the creek

$d = 1/8$ mile = 660 feet ≅ 202 m

≈ 7.6 years

4

Assume highest porosity reported $n = 0.32$

$$v_x = \frac{-2.0 \times 10^{-4} \text{ cm/sec}}{0.32} \left(-0.0418 \text{ cm/cm}\right)$$

$$v_x = 2.61 \times 10^{-5} \text{ cm/sec}$$

$$v_x = 0.0225 \text{ m/d}$$

$$t = \frac{202 \text{ m}}{0.03567 \text{ m/d}} \cong 21.5 \text{ years}$$

Assume Unoxidized Clay Layer travel

$$v_x = \frac{-2.0 \times 10^{-4} \text{ cm/sec}}{0.01} \left(-0.0906 \text{ cm/cm}\right)$$

$$v_x = 0.000836 \text{ cm/sec} \rightarrow 0.7223 \text{ m/d}$$

$$t = \frac{d}{v_x} = \frac{202 \text{ m}}{1.0454 \text{ m/d}} = \underline{\underline{280 \text{ days}}}$$

5

Dispersion Calculations

$$D_L = \alpha_L v_x + \cancel{D^*}^{\varnothing}$$

$$D_L = \frac{\sigma_x^2}{2t}$$ ← variance in concentrations along flow path

$$\alpha_L = \frac{\sigma_x^2}{2x}$$

See Excel Analysis of variance in concentrations from MW 2-4 (in line with GW flow) * using Cl^- as tracer mean $[Cl^-]$ for 2-4 wells

worst case:

Longitudinal $D_L = \frac{99.037 \cdot [illegible] \text{ m/d}}{2 \cdot (39.62\text{ m})^2} = \underline{\underline{0.903\ m^2/day}}$

dispersivity → $\alpha_L = \frac{\sigma_L^2}{2x} = \underline{\underline{1.25\text{ m}}}$ (Geol 534 0.1 m → 2 m OK.)

is fairly high

so K's aren't completely described over entire region

Peclet # = $\frac{v_x L}{D_L} = \frac{([illegible]\text{ m/d})(202\text{ m})}{0.903\ m^2/d} = 161.63$

P > 6 so advection-dispersion dominates flow system.

1-D Advection/Dispersion Equation:

Ogata and Banks (1961) solution:

Gets huge exp...

$$C(x,t) = \frac{C_o}{2}\left[ERFC\left(\frac{x - v_x t}{(4 D_L t)^{1/2}}\right) + \cancel{\exp\left(\frac{v_x x}{D_L}\right)ERFC\left(\frac{x + v_x t}{(4 D_L t)^{1/2}}\right)}\right]$$

C_o = Nitrate levels in well 3 = 9.2 mg/L (worst case)

find modeled conc at well 2 @ x = 66.7' or 20.32 m from well 3

1 month

$$C(20.32\,m, 1\,month) = \frac{9.2\,mg/L}{2}\left[ERFC\left(\frac{20.32\,m - [illegible] \cdot 30d}{(4 \cdot [illegible] \cdot 30d)^{1/2}}\right)\right]$$

$$= \frac{9.2}{2}\left[ERFC(-0.[illegible])\right]$$

$$= \frac{9.2\,mg/L}{2}\left[1 + ERF(0.1287)\right]$$

$$= \frac{9.2}{2}\left[1.144458\right]$$

$$= \underline{5.26}\ mg/L$$ (actual MW2 NO_3-N is lower → biological?)

Oct 1993 → June 1997 ≈ 1400 days

NO_3-N transport to creek: (1 yr) From lagoon.

$$C(202\,m, 1\,yr) = \frac{10\,mg/L}{2}\left[ERFC\left(\frac{202\,m - 0.[illegible]\,m/d \cdot 1\,yr}{(4 \cdot [illegible]\,m^2/d \cdot 1\,yr)^{1/2}}\right)\right]$$

$$= 5\left[ERFC(-1.[illegible])\right]$$

$$5\left[1.98[illegible]\right]$$

$$= \boxed{9.92\ mg/L}$$

Time for Nitrate-N to reach full impact at the creek:

Ogata and Banks Eqn

Given Information:

Time for Transport =	9509.864241	days
Initial Concentration =	9.2	mg/L
Distance to point of impact =	202	m
Dispersion =	0.903	m^2/day
Linear Velocity =	0.0722	m/day

Answers:

Positive ERFC:

Concentration (x,t) =	#NUM!	mg/L

Negative ERFC:

Concentration (x,t) =	9.1990	mg/L

Nitrate-N Concentration at creek (expected since 1993):

Ogata and Banks Eqn

Given Information:

Time for Transport =	1400	days
Initial Concentration =	9.2	mg/L
Distance to point of impact =	202	m
Dispersion =	0.903	m^2/day
Linear Velocity =	0.0722	m/day

Answers:

Positive ERFC:

Concentration (x,t) = 0.2058 mg/L

Negative ERFC:

Concentration (x,t) = N/A mg/L

Nitrate-N Concentration at creek (expected since Dec. 1996):

Ogata and Banks Eqn

Given Information:

Time for Transport =	183	days
Initial Concentration =	0.5	mg/L
Distance to point of impact =	202	m
Dispersion =	0.903	m^2/day
Linear Velocity =	0.0722	m/day

Answers:

Positive ERFC:

Concentration (x,t) =	0.0000	mg/L

Negative ERFC:

Concentration (x,t) =	N/A	mg/L

Estimate of aquifer travel times (Cl^- tracer)

	start time of increase	Date (Serial)
MW 4		
Cl^-	9/15/94	34592
MW 3		
Cl^-	7/18/95	34898
MW 2		
Cl^-	10/17/95	34989

Cl^-:

MW4 → MW3 = 306 days

MW3 → MW2 = 91 days

MW4→3 $V_{Cl^-} = \frac{X}{t} = \frac{63.5'}{306 \text{ days}} = 0.207 \text{ ft/d} \rightarrow 6.305 \text{ cm/d} = 7.3 \times 10^{-5} \text{ cm/sec}$

Ave = 0.143 m/d

MW3→2 $V_{Cl^-} = \frac{X}{t} = \frac{66.7'}{91 \text{ days}} = 0.733 \text{ ft/d} \rightarrow 22.34 \text{ cm/d} \rightarrow 2.58 \times 10^{-4} \text{ cm/sec}$

↓ use this one

$V_{Cl^-} = 0.223$ m/d

$2.58 \times 10^{-4} \text{ cm/sec} = 0.222912 \text{ m/d}$

time to stream = $t = \frac{202 \text{ m}}{0.222912 \text{ m/d}} = 906.2 \text{ days} = \underline{\underline{2.5 \text{ yr}}}$

Sodium Absorption Ratio Calculations

SAR Calculations

MW2:

$$SAR = \frac{[Na^{+}]}{\left(\frac{(Ca^{2+} + Mg^{2+})}{2}\right)^{1/2}} = \frac{\left[\frac{11}{23}\right]}{\left(\frac{\left(\frac{120}{20.04} + \frac{32}{12.15}\right)}{2}\right)^{1/2}}$$

SAR = 0.233

MW3:

$$SAR = \frac{\left[\frac{11}{23}\right]}{\left(\frac{\left(\frac{130}{20.04} + \frac{24}{12.15}\right)}{2}\right)^{0.5}} = 0.222$$

MW4:

$$SAR = \frac{\left[\frac{25}{23}\right]}{\left(\frac{\left(\frac{260}{20.04} + \frac{32}{12.15}\right)}{2}\right)^{1/2}} = 0.355$$

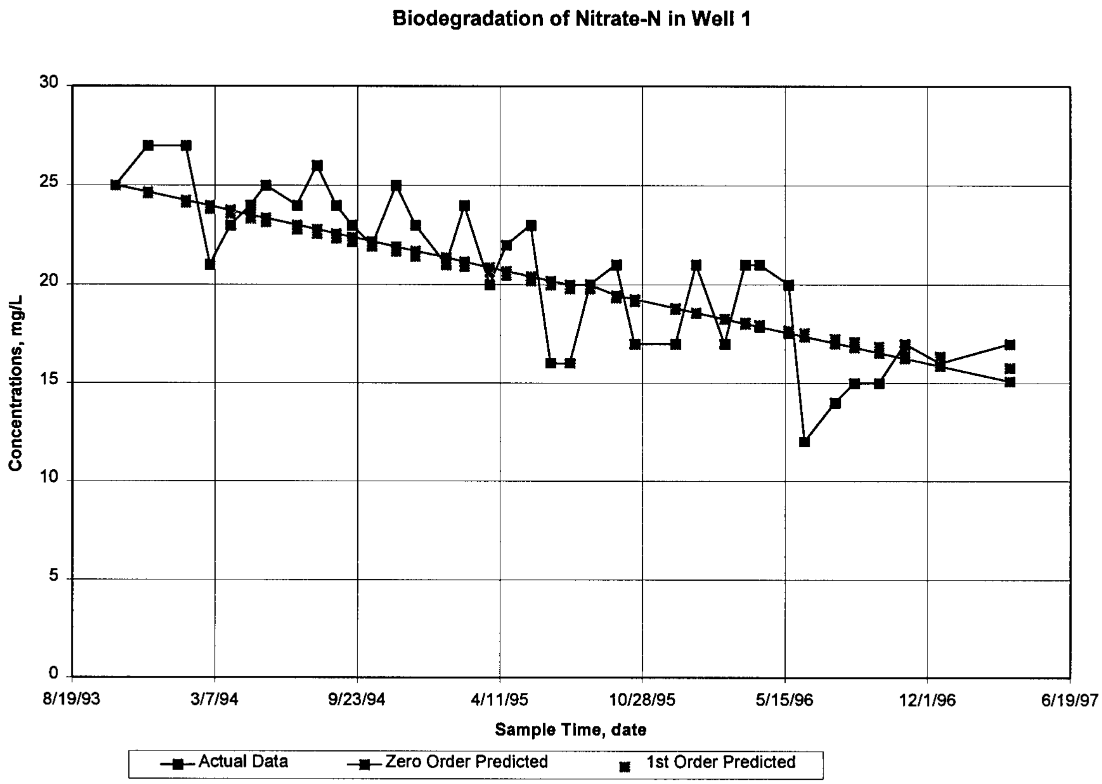
Ave = 0.27

Biological Degradation and Transport Data

Biodegradation of Nitrate-N in MW 1

K1 = 0.0004 Guessed by 'Solver'
K0 = 0.0079 Guessed by 'Solver'
X0 = 0 Guessed by 'Solver'
μ_{max} = 0.25 1/hr for denitrification
Initial Concentratio 25 mg/L of nitrate-N

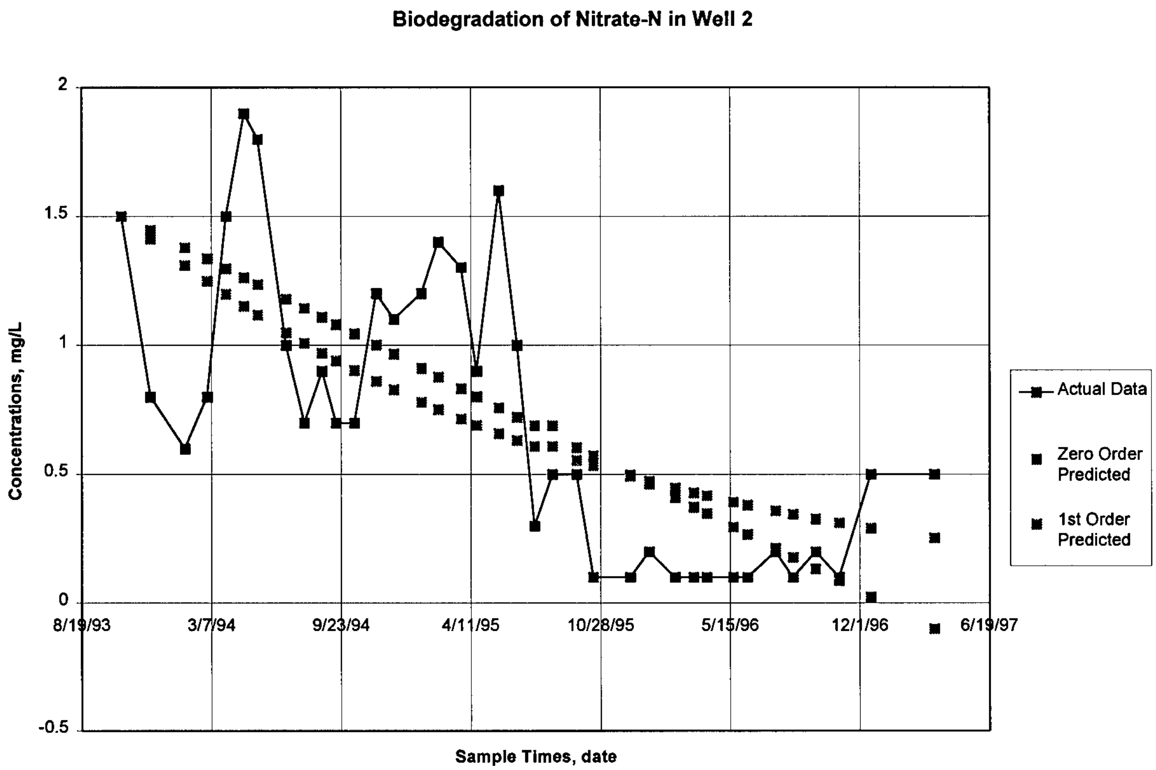
Actual Concentrations				Predicted Zero Order		Predicted 1st order	
Date/MW	Date	Days	MW1	MW1	Difference^2	MW1	Difference^2
10/19/93	34263	0	25	25	0.00	25	0.00
12/3/93	34306	43	27	24.65973	5.48	24.60799	5.72
1/25/94	34359	96	27	24.24032	7.62	24.13327	8.22
2/28/94	34393	130	21	23.97127	8.83	23.83356	8.03
3/29/94	34422	159	23	23.74178	0.55	23.58087	0.34
4/26/94	34450	187	24	23.52021	0.23	23.33944	0.44
5/17/94	34471	208	25	23.35403	2.71	23.15999	3.39
6/30/94	34515	252	24	23.00584	0.99	22.78845	1.47
7/28/94	34543	280	26	22.78427	10.34	22.55513	11.87
8/24/94	34570	307	24	22.57061	2.04	22.33241	2.78
9/15/94	34592	329	23	22.39652	0.36	22.15255	0.72
10/13/94	34620	357	22	22.17494	0.03	21.92574	0.01
11/16/94	34654	391	25	21.90589	9.57	21.65345	11.20
12/13/94	34681	418	23	21.69223	1.71	21.43963	2.43
1/25/95	34724	461	21	21.35196	0.12	21.10345	0.01
2/20/95	34750	487	24	21.14621	8.14	20.90274	9.59
3/27/95	34785	522	20	20.86925	0.76	20.63557	0.40
4/20/95	34809	546	22	20.67933	1.74	20.45434	2.39
5/24/95	34843	580	23	20.41027	6.71	20.20032	7.84
6/21/95	34872	609	16	20.18079	17.48	19.98615	15.89
7/18/95	34898	635	16	19.97504	15.80	19.79607	14.41
8/15/95	34898	635	20	19.97504	0.00	19.79607	0.04
9/21/95	34963	700	21	19.46067	2.37	19.32873	2.79
10/17/95	34989	726	17	19.25493	5.08	19.1449	4.60
12/13/95	35046	783	17	18.80387	3.25	18.74799	3.06
1/11/96	35075	812	21	18.57438	5.88	18.54922	6.01
2/20/96	35115	852	17	18.25785	1.58	18.2785	1.63
3/20/96	35144	881	21	18.02836	8.83	18.08471	8.50
4/9/96	35164	901	21	17.8701	9.80	17.95226	9.29
5/20/96	35205	942	20	17.54565	6.02	17.68375	5.36
6/11/96	35227	964	12	17.37156	28.85	17.54134	30.71
7/24/96	35270	1007	14	17.03128	9.19	17.26629	10.67
8/20/96	35297	1034	15	16.81762	3.30	17.09579	4.39
9/24/96	35332	1069	15	16.54066	2.37	16.87727	3.52
10/30/96	35368	1105	17	16.25578	0.55	16.65543	0.12
12/18/96	35417	1154	16	15.86803	0.02	16.35815	0.13
3/26/97	35515	1252	17	15.09252	3.64	15.77942	1.49
					191.97		199.45


Biodegradation of Nitrate-N in Well 1
30
25
20
15
10
5
0
Concentrations, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Time, date
Actual Data
Zero Order Predicted
1st Order Predicted

Biodegradation of Nitrate-N in MW 2

K1 = 0.00142 Guessed by 'Solver'
K0 = 0.001278 Guessed by 'Solver'
X0 = 0 Guessed by 'Solver'
μ_{max} = 0.25 1/hr for denitrification
Initial Concentration = 1.5 mg/L of nitrate-N

Actual Concentrations				Predicted Zero Order		Predicted 1st order	
Date/MW	Date	Days	MW2	MW2	Difference^2	MW2	Difference^2
10/19/93	34263	0	1.5	1.5	0.00	1.5	0.00
12/3/93	34306	43	0.8	1.44504	0.42	1.411157	0.37
1/25/94	34359	96	0.6	1.377298	0.60	1.30886	0.50
2/28/94	34393	130	0.8	1.333842	0.28	1.247175	0.20
3/29/94	34422	159	1.5	1.296776	0.04	1.196863	0.09
4/26/94	34450	187	1.9	1.260988	0.41	1.150213	0.56
5/17/94	34471	208	1.8	1.234147	0.32	1.116423	0.47
6/30/94	34515	252	1	1.177908	0.03	1.048809	0.00
7/28/94	34543	280	0.7	1.14212	0.20	1.00793	0.09
8/24/94	34570	307	0.9	1.107611	0.04	0.970021	0.00
9/15/94	34592	329	0.7	1.079492	0.14	0.940188	0.06
10/13/94	34620	357	0.7	1.043704	0.12	0.903543	0.04
11/16/94	34654	391	1.2	1.000247	0.04	0.860959	0.11
12/13/94	34681	418	1.1	0.965737	0.02	0.828578	0.07
1/25/95	34724	461	1.2	0.910777	0.08	0.779502	0.18
2/20/95	34750	487	1.4	0.877545	0.27	0.75125	0.42
3/27/95	34785	522	1.3	0.83281	0.22	0.714829	0.34
4/20/95	34809	546	0.9	0.802135	0.01	0.69088	0.04
5/24/95	34843	580	1.6	0.758678	0.71	0.658319	0.89
6/21/95	34872	609	1	0.721612	0.08	0.631762	0.14
7/18/95	34898	635	0.3	0.68838	0.15	0.608865	0.10
8/15/95	34898	635	0.5	0.68838	0.04	0.608865	0.01
9/21/95	34963	700	0.5	0.605301	0.01	0.555187	0.00
10/17/95	34989	726	0.1	0.572069	0.22	0.535065	0.19
12/13/95	35046	783	0.1	0.499215	0.16	0.493466	0.15
1/11/96	35075	812	0.2	0.462149	0.07	0.47356	0.07
2/20/96	35115	852	0.1	0.411024	0.10	0.447413	0.12
3/20/96	35144	881	0.1	0.373958	0.08	0.429364	0.11
4/9/96	35164	901	0.1	0.348395	0.06	0.417343	0.10
5/20/96	35205	942	0.1	0.295991	0.04	0.393741	0.09
6/11/96	35227	964	0.1	0.267872	0.03	0.381632	0.08
7/24/96	35270	1007	0.2	0.212912	0.00	0.359028	0.03
8/20/96	35297	1034	0.1	0.178402	0.01	0.345525	0.06
9/24/96	35332	1069	0.2	0.133667	0.00	0.328773	0.02
10/30/96	35368	1105	0.1	0.087654	0.00	0.31239	0.05
12/18/96	35417	1154	0.5	0.025025	0.23	0.291395	0.04
3/26/97	35515	1252	0.5	-0.10023	0.36	0.253542	0.06
					5.58		5.87

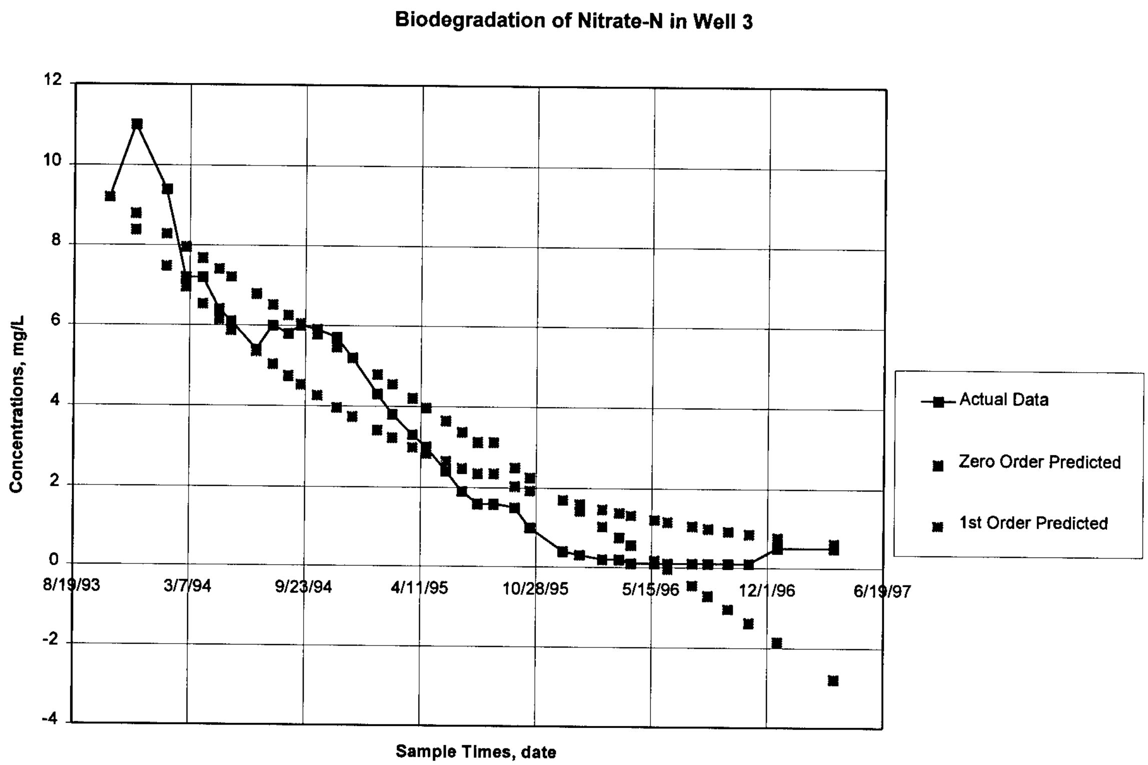


Biodegradation of Nitrate-N in Well 2
2
1.5
1
0.5
0
-0.5
Concentrations, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, date
Actual Data
Zero Order Predicted
1st Order Predicted

Biodegradation of Nitrate-N in MW 3

K1 = 0.002156 Guessed by 'Solver'
K0 = 0.009582 Guessed by 'Solver'
X0 = 0 Guessed by 'Solver'
μ_{max} = 0.25 1/hr for denitrification
Initial Concentration 9.2 mg/L of nitrate-N

Actual Concentrations				Predicted Zero Order		Predicted 1st order	
Date/MW	Date	Days	MW3	MW3	Difference^2	MW3	Difference^2
10/19/93	34263	0	9.2	9.2	0.00	9.2	0.00
12/3/93	34306	43	11	8.787988	4.89	8.385416	6.84
1/25/94	34359	96	9.4	8.280159	1.25	7.479936	3.69
2/28/94	34393	130	7.2	7.954382	0.57	6.951233	0.06
3/29/94	34422	159	7.2	7.676513	0.23	6.529916	0.45
4/26/94	34450	187	6.4	7.408226	1.02	6.147374	0.06
5/17/94	34471	208	6.1	7.20701	1.23	5.875249	0.05
6/30/94	34515	252	5.4	6.785416	1.92	5.343511	0.00
7/28/94	34543	280	6	6.517129	0.27	5.030472	0.94
8/24/94	34570	307	5.8	6.258424	0.21	4.745994	1.11
9/15/94	34592	329	6	6.047627	0.00	4.526134	2.17
10/13/94	34620	357	5.9	5.77934	0.01	4.26098	2.69
11/16/94	34654	391	5.7	5.453563	0.06	3.959802	3.03
12/13/94	34681	418	5.2	5.194857	0.00	3.735872	2.14
1/25/95	34724	461	4.3	4.782845	0.23	3.405091	0.80
2/20/95	34750	487	3.8	4.533721	0.54	3.219464	0.34
3/27/95	34785	522	3.3	4.198363	0.81	2.985459	0.10
4/20/95	34809	546	3	3.968402	0.94	2.834906	0.03
5/24/95	34843	580	2.4	3.642625	1.54	2.634527	0.06
6/21/95	34872	609	1.9	3.364756	2.15	2.474847	0.33
7/18/95	34898	635	1.6	3.115633	2.30	2.339932	0.55
8/15/95	34898	635	1.6	3.115633	2.30	2.339932	0.55
9/21/95	34963	700	1.5	2.492823	0.99	2.03395	0.29
10/17/95	34989	726	1.0	2.2437	1.55	1.92307	0.85
12/13/95	35046	783	0.4	1.697544	1.68	1.700681	1.69
1/11/96	35075	812	0.3	1.419675	1.25	1.597602	1.68
2/20/96	35115	852	0.2	1.036408	0.70	1.465596	1.60
3/20/96	35144	881	0.2	0.758539	0.31	1.376766	1.38
4/9/96	35164	901	0.1	0.566906	0.22	1.318661	1.49
5/20/96	35205	942	0.1	0.174057	0.01	1.207098	1.23
6/11/96	35227	964	0.1	-0.03674	0.02	1.151179	1.10
7/24/96	35270	1007	0.1	-0.44875	0.30	1.049251	0.90
8/20/96	35297	1034	0.1	-0.70746	0.65	0.989915	0.79
9/24/96	35332	1069	0.1	-1.04282	1.31	0.917964	0.67
10/30/96	35368	1105	0.1	-1.38776	2.21	0.849409	0.56
12/18/96	35417	1154	0.5	-1.85726	5.56	0.76425	0.07
3/26/97	35515	1252	0.5	-2.79626	10.87	0.61869	0.01
					50.08		40.30

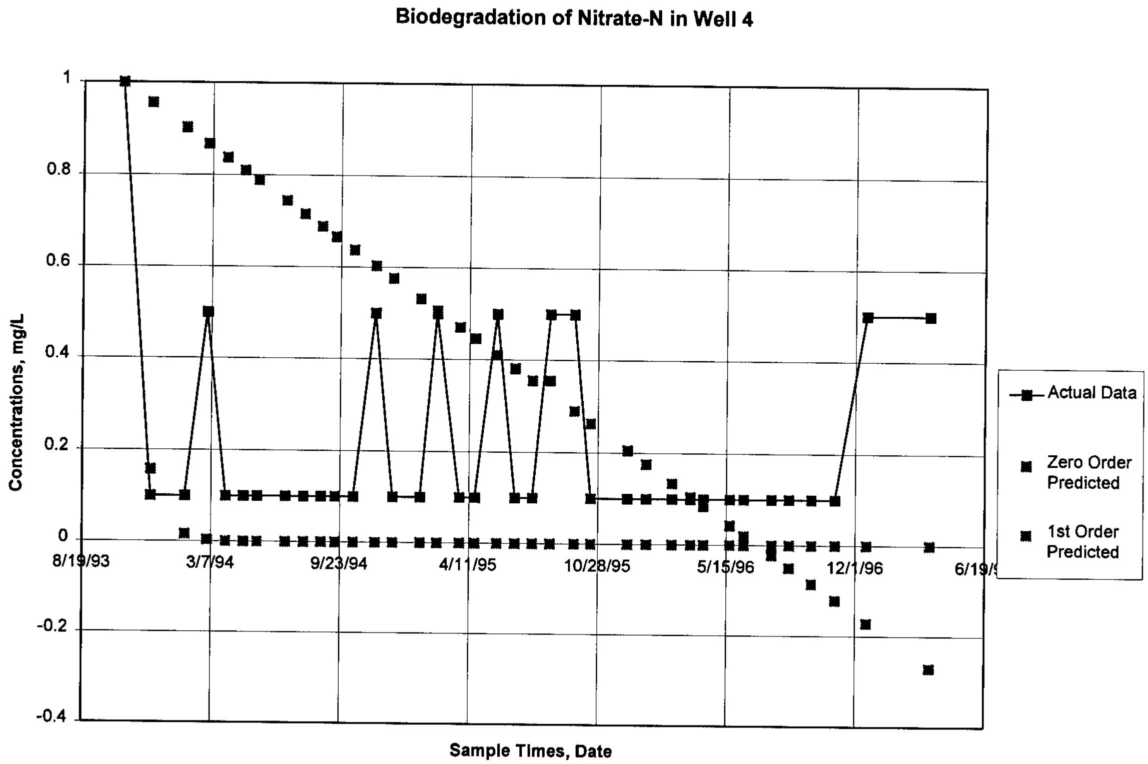


Biodegradation of Nitrate-N in Well 3
12
10
8
6
4
2
0
-2
-4
Concentrations, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, date
Actual Data
Zero Order Predicted
1st Order Predicted

Biodegradation of Nitrate-N in MW 4

K1 = 0.042906 Guessed by 'Solver'
K0 = 0.001016 Guessed by 'Solver'
X0 = 0 Guessed by 'Solver'
μ_{max} = 0.25 1/hr for denitrification
Initial Concentration 1 mg/L of nitrate-N

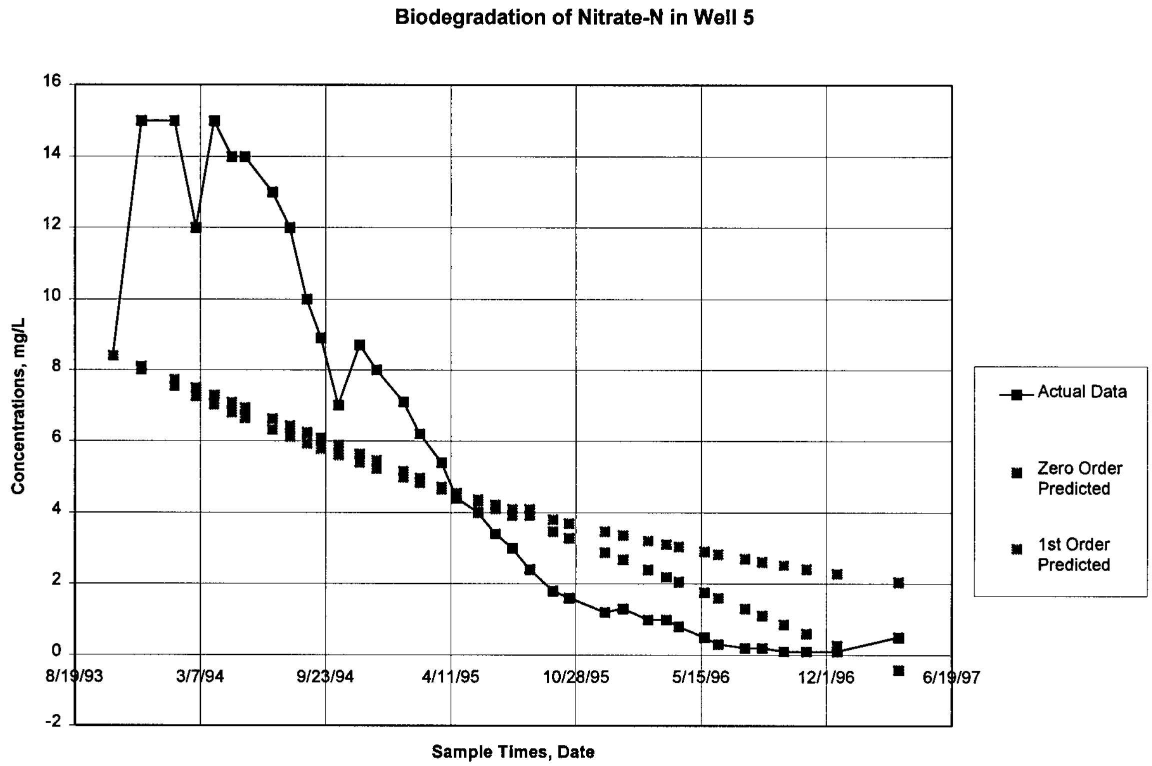
Actual Concentrations				Predicted Zero Order		Predicted 1st order	
Date/MW	Date	Days	MW4	MW4	Difference^2	MW4	Difference^2
10/19/93	34263	0	1	1	0.00	1	0.00
12/3/93	34306	43	0.1	0.956327	0.73	0.15803	0.00
1/25/94	34359	96	0.1	0.902497	0.64	0.016261	0.01
2/28/94	34393	130	0.5	0.867964	0.14	0.003781	0.25
3/29/94	34422	159	0.1	0.83851	0.55	0.001089	0.01
4/26/94	34450	187	0.1	0.810072	0.50	0.000328	0.01
5/17/94	34471	208	0.1	0.788743	0.47	0.000133	0.01
6/30/94	34515	252	0.1	0.744054	0.41	2.01E-05	0.01
7/28/94	34543	280	0.1	0.715616	0.38	6.06E-06	0.01
8/24/94	34570	307	0.1	0.688193	0.35	1.9E-06	0.01
9/15/94	34592	329	0.1	0.665849	0.32	7.4E-07	0.01
10/13/94	34620	357	0.1	0.63741	0.29	2.23E-07	0.01
11/16/94	34654	391	0.5	0.602878	0.01	5.18E-08	0.25
12/13/94	34681	418	0.1	0.575455	0.23	1.63E-08	0.01
1/25/95	34724	461	0.1	0.531782	0.19	2.57E-09	0.01
2/20/95	34750	487	0.50	0.505375	0.00	8.42E-10	0.25
3/27/95	34785	522	0.10	0.469827	0.14	1.88E-10	0.01
4/20/95	34809	546	0.10	0.445451	0.12	6.7E-11	0.01
5/24/95	34843	580	0.50	0.410918	0.01	1.56E-11	0.25
6/21/95	34872	609	0.10	0.381464	0.08	4.49E-12	0.01
7/18/95	34898	635	0.10	0.355057	0.07	1.47E-12	0.01
8/15/95	34898	635	0.50	0.355057	0.02	1.47E-12	0.25
9/21/95	34963	700	0.50	0.289039	0.04	9.04E-14	0.25
10/17/95	34989	726	0.10	0.262632	0.03	2.96E-14	0.01
12/13/95	35046	783	0.10	0.20474	0.01	2.57E-15	0.01
1/11/96	35075	812	0.10	0.175286	0.01	7.4E-16	0.01
2/20/96	35115	852	0.10	0.134659	0.00	1.33E-16	0.01
3/20/96	35144	881	0.10	0.105205	0.00	3.83E-17	0.01
4/9/96	35164	901	0.10	0.084892	0.00	1.62E-17	0.01
5/20/96	35205	942	0.10	0.04325	0.00	2.8E-18	0.01
6/11/96	35227	964	0.10	0.020906	0.01	1.09E-18	0.01
7/24/96	35270	1007	0.10	-0.02277	0.02	1.72E-19	0.01
8/20/96	35297	1034	0.10	-0.05019	0.02	5.4E-20	0.01
9/24/96	35332	1069	0.10	-0.08574	0.03	1.2E-20	0.01
10/30/96	35368	1105	0.10	-0.1223	0.05	2.57E-21	0.01
12/18/96	35417	1154	0.50	-0.17207	0.45	3.14E-22	0.25
3/26/97	35515	1252	0.50	-0.2716	0.60	4.68E-24	0.25
					6.90		2.27


Biodegradation of Nitrate-N in Well 4
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Concentrations, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/
Sample Times, Date
Actual Data
Zero Order Predicted
1st Order Predicted

Biodegradation of Nitrate-N in MW 5

K1 = 0.00113 Guessed by 'Solver'
K0 = 0.007049 Guessed by 'Solver'
X0 = 0 Guessed by 'Solver'
μ_{max} = 0.25 1/hr for denitrification
Initial Concentration 8.4 mg/L of nitrate-N

Actual Concentrations				**Predicted Zero Order**		**Predicted 1st order**	
Date/MW	Date	Days	MW5	MW5	Difference^2	MW5	Difference^2
10/19/93	34263	0	8.4	8.4	0.00	8.4	0.00
12/3/93	34306	43	15	8.09688	47.65	8.001533	48.98
1/25/94	34359	96	15	7.723268	52.95	7.53631	55.71
2/28/94	34393	130	12	7.483592	20.40	7.252208	22.54
3/29/94	34422	159	15	7.279163	59.61	7.018364	63.71
4/26/94	34450	187	14	7.081783	47.86	6.799742	51.84
5/17/94	34471	208	14	6.933747	49.93	6.640256	54.17
6/30/94	34515	252	13	6.623579	40.66	6.31812	44.65
7/28/94	34543	280	12	6.426199	31.07	6.12131	34.56
8/24/94	34570	307	10	6.235868	14.17	5.937338	16.51
9/15/94	34592	329	8.9	6.080783	7.95	5.79153	9.66
10/13/94	34620	357	7.00	5.883403	1.25	5.611123	1.93
11/16/94	34654	391	8.7	5.643727	9.34	5.399596	10.89
12/13/94	34681	418	8.00	5.453396	6.49	5.237314	7.63
1/25/95	34724	461	7.1	5.150277	3.80	4.988874	4.46
2/20/95	34750	487	6.2	4.966995	1.52	4.844408	1.84
3/27/95	34785	522	5.4	4.72027	0.46	4.656519	0.55
4/20/95	34809	546	4.4	4.551087	0.02	4.53191	0.02
5/24/95	34843	580	4	4.311411	0.10	4.361067	0.13
6/21/95	34872	609	3.4	4.106982	0.50	4.220446	0.67
7/18/95	34898	635	3.0	3.9237	0.85	4.098232	1.21
8/15/95	34898	635	2.4	3.9237	2.32	4.098232	2.88
9/21/95	34963	700	1.8	3.465496	2.77	3.807957	4.03
10/17/95	34989	726	1.6	3.282215	2.83	3.697688	4.40
12/13/95	35046	783	1.2	2.880405	2.82	3.466989	5.14
1/11/96	35075	812	1.3	2.675976	1.89	3.355197	4.22
2/20/96	35115	852	1.0	2.394004	1.94	3.206893	4.87
3/20/96	35144	881	1	2.189575	1.42	3.103489	4.42
4/9/96	35164	901	0.8	2.048589	1.56	3.034125	4.99
5/20/96	35205	942	0.5	1.759568	1.59	2.896737	5.74
6/11/96	35227	964	0.3	1.604484	1.70	2.825599	6.38
7/24/96	35270	1007	0.2	1.301364	1.21	2.691563	6.21
8/20/96	35297	1034	0.2	1.111033	0.83	2.610669	5.81
9/24/96	35332	1069	0.1	0.864308	0.58	2.509415	5.81
10/30/96	35368	1105	0.1	0.610533	0.26	2.409363	5.33
12/18/96	35417	1154	0.1	0.265118	0.03	2.279561	4.75
3/26/97	35515	1252	0.5	-0.42571	0.86	2.040558	2.37
					421.20		509.02


Biodegradation of Nitrate-N in Well 5
16
14
12
10
8
6
4
2
0
-2
Concentrations, mg/L
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
Sample Times, Date
Actual Data
Zero Order Predicted
1st Order Predicted

Biological Degradation and Transport Calculations

8

Steady-State biodegradation of Nitrate in aquifer: (Well 3-4) to Stream

Well 3: $C = C_0 \exp\left[\left(\frac{x}{2\alpha_x}\right)\left(1-\left(1+\frac{4K_1\alpha_x}{v_x}\right)^{1/2}\right)\right]$

$= 9.2\ mg/L\ \exp\left[\left(\frac{[illegible]\ m}{(2)(1.25\ m)}\right)\left(1-\left(1+\frac{(4)(0.[illegible]\ 1/d)(1.25\ m)}{0.[illegible]\ m/d}\right)^{1/2}\right)\right]$

$= 9.2\ mg/L\ \exp\left[\left([illegible].4\right)\left(-0.097735\ldots\right)\right]$

$= 9.2\ mg/L\ (0.5[illegible]) = 5.37\ mg/L$ at start of Lagoon

Now

$= 0.5\ mg/L\ (0.00542) = \underline{\underline{0.[illegible]\ mg/L}}$ NO_3-N

Well 4:

$C = 1\ mg/L\ \exp\left[(30.8)\left(1-\left(1+\frac{(4)(0.04291\ 1/d)(1.25\ m)}{0.[illegible]\ m/d}\right)^{1/2}\right)\right]$

$= 1\ mg/L\ \exp\left[(30.8)(-0.[illegible])\right]$

$C = 1.34 \times 10^{-5}\ mg/L$ or $\underline{\underline{13.4\ ppt}}$ NO_3-N at start of Lagoon

Now:

$= 0.7\ mg/L\ \left(\exp(30.8)(-0.09787)\right)$

$= 9.375 \times 10^{-6}\ mg/L$ or 9.375 ppt NO_3-N Now

APPENDIX I: Health Hazard Calculations

Health Hazard Data

<u>Human Health effects:</u>

Well 4 Data as of 3/26/97

M-Fecal = < 2
NO_3-N = 0.5 mg/L
Ammonia-N = 1 mg/L
Organic-N = 0.1 mg/L
TOC = 29 mg/L
Fl$^-$ = 0.54 mg/L
Cl$^-$ = 330 mg/L ☆ only problem
HPO_4^- = 0.5 mg/L
$SO_4^{=}$ = 2.8 mg/L
Br$^-$ = 0.89 mg/L

<u>Intake NH_3</u> (Daily water intake rate = 2L/d
Body weight (adult) = 70 kg)

Conc NH_3-N = 1 mg/L

Health Hazard Calculations

Health Hazards of Selected Chemicals

Daily water intake rate =	2	L/day
Body weight =	70	kg

Substance	Concentration, mg/L	Dose, mg/kg*day	RfD, (mg/kg*day)	Hazard Ratio, dose/RfD
Nitrate	0.5	0.014285714	1.6	0.008928571
~Nitrite	0.1	0.002857143	0.1	0.028571429
Fluoride	0.54	0.015428571	0.06	0.257142857
Totals		0.032571429		0.294642857

*less than EPA hazard index of 1 so OK
*hazard rating (greatest risk to lowest risk): children 6-12, children 2-6, adults

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BIOGRAPHICAL SKETCH

Scott Ryan Mattes was born on December 5, 1973 in Logansport, Indiana. In May of 1996, he graduated from the United States Air Force Academy as a "Distinguished Graduate" with a Bachelor of Science degree in Civil (Environmental) Engineering. He was awarded one of 23 scholarships to attend graduate school with the purpose of attaining a Master of Science degree in Civil Engineering. This degree will allow him to become an instructor for the Department of Civil and Environmental Engineering at the United States Air Force Academy. Following graduation, Scott earned one, out of seven total positions available, into the Biomedical Science Corps (BSC). He will serve in the BSC as a Bioenvironmental Engineer.

As a Bioenvironmental Engineer, Scott will eventually transfer to Wright-Patterson Air Force Base, where he will work for the 74th Medical Squadron after completing his Master's degree at Iowa State University. Scott, a native of Clarinda, Iowa, was married in December of 1996 to his beautiful bride, Kimberly, a native of Colorado Springs, Colorado.